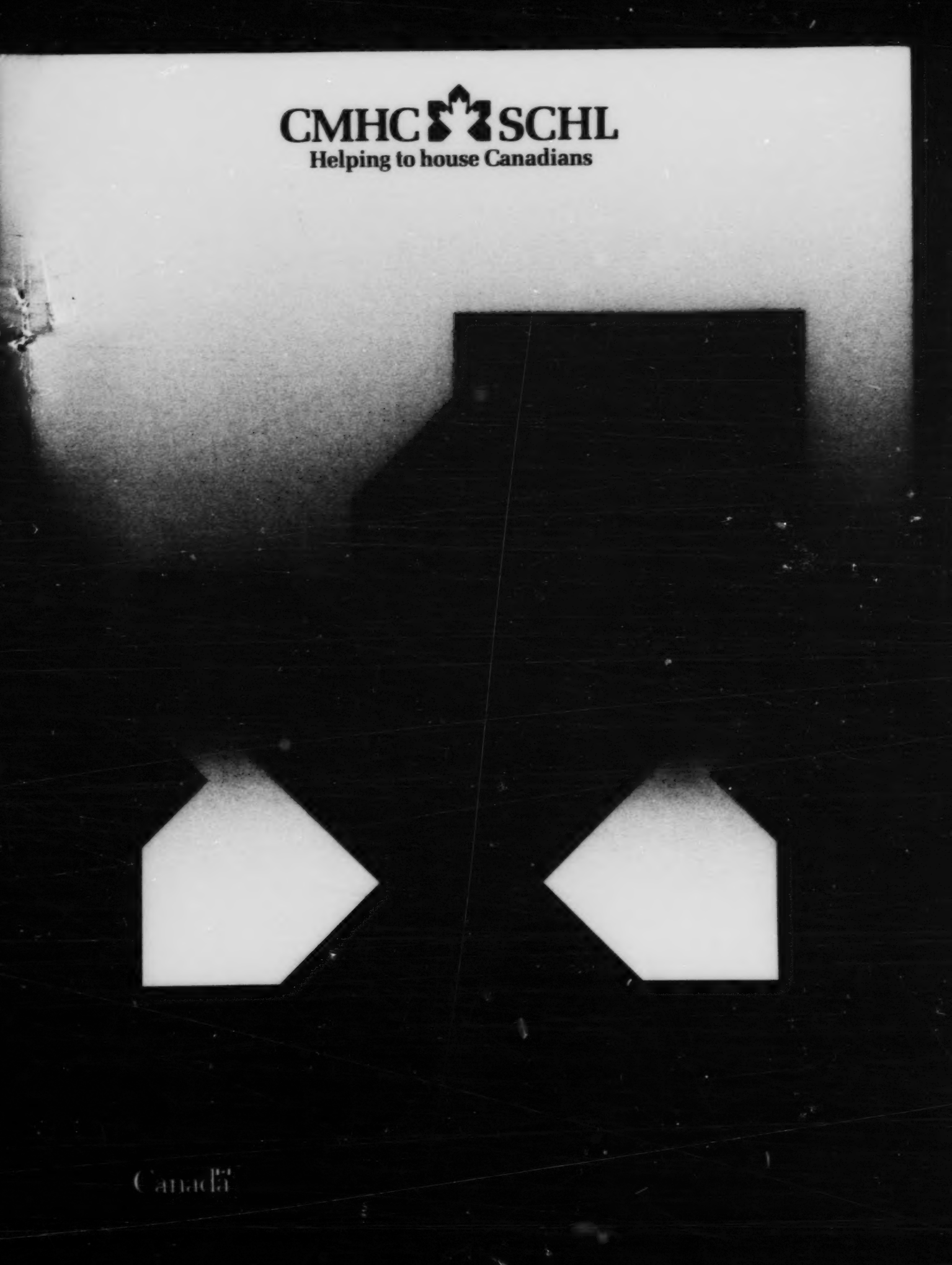
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FIELD EVALUATION OF FOUNDATION DRAIN RESPONSE

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with funding provided by the

Canada Mortgage and Housing Corporation / Société canadienne d'hypothèques et de logement

1989 December

prepared by

CH2M HILL ENGINEERING LTD.

The views and conclusions expressed and the recommendations made in this report are entirely those of authors and should not be construed as expressing the opinions of the Canada Mortgage and Housing Corporation.

ABSTRACT

A study was carried out in Edmonton during the summer of 1989 to monitor the response of foundation drain flows to simulated rainfall events. The simulated precipitation was based on 50-year return period design storms. The quantity of water applied was recorded and the foundation drain response was calculated based on sump pump running time records. The calculated response varied from 0.07 to 0.49 L/s over 19 simulations. Data collected in the field testing were input into a foundation drain response model previously developed by CH2M HILL. This report also discusses foundation drain design allowances, discharge alternatives, and sump capacity.

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EXECUTIVE SUMMARY

INTRODUCTION

A study was carried out by CH2M HILL ENGINEERING LTD. in Edmonton in 1989 to observe the response of foundation drains to rainfall events. Studies previously conducted in other areas indicated that foundation drains could contribute high flows to sewer systems as a result of rainfall. Significant occurrences of sewer surcharging and basement flooding caused by rainfall events have been observed throughout North America, but no firm values for foundation drain contributions have been derived.

OBJECTIVES

In this study, 50-year return period storms were simulated on selected residential lots in Edmonton, on which houses were equipped with a sump and pump. A short duration (3-hour) and a long duration (8-hour) storm were simulated for dry and wet antecedent conditions on each lot.

One objective of the program was to compare actual observed results with results predicted by a mathematical model previously developed by CH2M HILL. Model input data were gathered during the test program.

METHODOLOGY

The flows onto the lot and roof surfaces and the discharge from the sump pumps were recorded during each simulation and, to observe the tail effect of each simulation, measurements were made for a period afterward. The data recorded, along with physical measurements on the lots, were used to calculate the rate of flow into the sumps. The data collected from 19 simulations were used to produce total inflow and response inflow hydrographs.

FINDINGS

The peak recorded inflow rates ranged from 0.07 L/s to 0.49 L/s. Peak flows of over 0.4 L/s resulted on two lots.

The percentage of precipitation entering the sumps spanned a range of 6.4 percent to 27.3 percent with roof leaders installed properly.

The data collected through investigations on the lots and recorded during the simulations were utilized in a foundation drain response model previously developed by CH2M HILL. The ratios of recorded to modeled flows varied from 0.37 to 1.89 with an average of 0.84. In general, the model predicted higher flows than those observed.

CONCLUSIONS

The results of this study confirm the significance of foundation drain contributions to sewer systems. The flows resulting from the simulations can exceed typical peak design sanitary flows and also exceed design allowances for foundation drains made by many municipalities.

A number of potential discharge alternatives exist for foundation drains as they are incorporated in the design of stormwater management systems:

- Sanitary sewers
- Storm sewers
- Sump pumps
- Third-line sewer system dedicated to foundation drain flows

Each system design has advantages and disadvantages in relation to public and private perceptions. Careful consideration must be given to choosing the appropriate system to reduce the impact of foundation drain discharge on public systems as well as on private individuals.

Sump pumps are becoming more widely used to discharge foundation drain flows. Sump pits and sump pumps should be designed as part of the house-as-a-system within the overall infrastructure system, not just as individual components. Considerable variability of inflow rates and pump capacities was observed during the course of this study, even in sites close to each other. Poorly designed or constructed discharges and homeowner maintenance practices can cause inconvenience and problems such as pump failure, winter ice buildup, and water-saturated lot areas.

Many questions regarding foundation drains remain to be answered. It would be beneficial to municipalities and the housing industry to carry out further studies directed at answering these questions. Research that would allow the isolation and control of various factors contributing to foundation drain flows would lead to a better understanding of the items which have the most significant impact on the overall basement drainage system.

1.0 INTRODUCTION

This study was undertaken to provide data to determine foundation drain flows resulting from rainfall.

At present, the design flow allowances for the foundation drain component of flows into sewers, sanitary or storm, vary widely throughout North America. Significant sewer surcharging and basement flooding caused by rainfall events have been observed throughout North America. The determination of a safe and acceptable design value for foundation drain flows is currently of major interest to the residential construction industry and in the agencies responsible for regulation of design standards.

1.1 Simulation Program

In this study a number of residential lots were selected and rainfall simulations were carried out. Fifty-year return period storms were simulated. Four simulations were carried out on each lot:

(a) A short-duration (3-hour), 50-year return period, dry antecedent conditions

(b) A short-duration (3-hour), 50-year return period, wet antecedent conditions

(c) A long-duration (8-hour), 50-year return period, dry antecedent conditions

(d) A long-duration (8-hour), 50-year return period, wet antecedent conditions

The flow onto the lots and roof surfaces was recorded as was the flow out of the foundation drains. The data recorded were used to calculate the foundation drain inflow rate for individual residences. Physical data were collected and provided input to a mathematical model previously developed by CH2M HILL to predict foundation drain flows for each site.

Verification of the model was attempted by comparing modeling results with recorded foundation drain through measurements from actual simulations.

1.2 Modeling of Simulated Rainfall

CH2M HILL has developed a model to predict foundation drain response to rainfall. The model was used to estimate foundation drain flows in an infiltration/inflow study. Data obtained in this study were used in the model to calculate foundation drain flowrates.

1.2.1 Model Description

The model considers the flow through the backfill zone around the house to the foundation drains.

Relationships that are required to calculate the drain flow are:

- Water depth above drain vs drain flows
- Infiltration rate vs rate of water table increase

The assumption is that the groundwater table is increased in the backfill zone and this provides the driving head on the flows.

A number of background calculations are required to enable the drain flows to be computed.

Darcy's Law is used to calculate flows into the foundation drain for a chosen soil conductivity (K).

Infiltration rates were calculated for the soil permeability which enabled calculation of the change in groundwater elevation.

The rational method is used in calculation of lot and roof contributions to the foundation drain flow. The rational method calculated runoff based on area,

rainfall intensity, and a runoff factor C. In this situation the runoff calculated is the inflow in the model.

1.3 Report Outline

This report discusses the following topics:

- Review of current foundation drain standards, design guidelines, and several previous studies
- The test program carried out in Edmonton in 1989
- Analysis of the data obtained in the study
- Modeled inflow and results
- Conclusions and recommendations arising from the study

Appendix A includes a summary of lot conditions for each test site and figures showing inflow hydrographs for each simulation.

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2.0 REVIEW OF EXISTING PRACTICE FOR FOUNDATION DRAIN DISCHARGE

Municipalities throughout Canada and the U.S. deal with foundation drain discharge by using various methods.

CH2M HILL has reviewed weeping tile connection policies for 19 municipalities in Ontario. Of these, only two, Windsor and North York, allowed discharge to sanitary sewers. St. Catharines requires connection to storm sewers under normal circumstances; however, if this is not feasible connection to sanitary sewers is approved. The other 16 municipalities reviewed require connections to storm sewers, sump pumps, or "third-line" systems.

Some specify that the sump pump should discharge to the storm sewer. Winnipeg requires sump pits with sump pumps in all buildings with basements installed since 1987. Foundation drain flows are to discharge to grade.

In Chicago, foundation drains are required to be connected to sump pumps with discharge to storm sewer systems or drainage ditches.

Ontario Ministry of the Environment and Ontario Municipal Engineers Association standards state that connection of foundation drains to sanitary sewers is discouraged or not recommended.

In the City of Edmonton, the requirements for foundation drain discharge have changed over time. In the City's design guidelines for 1972, 1974, 1976, and 1982, foundation drains were to be connected to the sanitary sewer system. In the 1986 guidelines, weeping tile discharge locations are listed as sanitary sewers, storm sewers, or ground level via sump pump. The 1988 standard disallows foundation drains discharge to sanitary sewers.

2.1 Alberta Building Code Requirements for Foundation Drains

Requirements for foundation drainage as per the Alberta Building Code are summarized as follows:

- Exterior footing drainage is to be provided via drainage tile or pipe laid around the exterior of the foundation, or a layer of crushed rock or gravel.
- Specifications to which various allowable materials must conform are listed.
- The minimum diameter of a foundation drain pipe is 100 mm.
- Foundation drain pipe is to be laid so that the top of the drain pipe is below the bottom of the floor slab.
- Coarse, clean granular cover 150 mm deep is to be provided on top and on the sides of the foundation drain pipe.
- If granular material alone is to be used, it must extend at least 125 mm below the building and 300 mm from the outside edge of the footings.
- The foundation drain shall discharge to a building drain, storm drain, drainage ditch, dry well, or ground surface.
- If sumps are provided, minimum dimensions are 750 mm deep and a surface area of 0.25 m^2. An automatic sump pump is required where gravity drainage is not feasible.

2.2 Review of Previous Tests

Where foundation drains are connected to the sanitary collection system, the quantification of resulting flows has been frequently investigated and, in several instances, field tests carried out. Studies carried out by various municipal and provincial

organizations in three areas to investigate the topic are reviewed and summarized below.

2.2.1 Winnipeg

Studies carried out in Winnipeg (1,2) were directed at determining the magnitude of flows, the relationship between weeping tile flows and rainfall, the effects of on-lot practices, and the contribution from roof leader flows. Seven lots were observed.

The program was intended to focus on natural rainfall events. The rainfall for the year (1972) was, however, lower than normal and additional testing involving roof leader flows was carried out. Uniform rates of flow were applied to roofs and the results recorded. The rates and discharge locations were varied.

The on-lot apparatus consisted of a pump with an electronic strip chart recorder. A network of seven municipally operated raingauges was used to determine rainfall at the particular sites. Each test site had one raingauge in its area.

The data recorded were analyzed; the following is a summary of test results:

- Time lapse from start of rainfall to start of drain flow varies from zero to more than 1 hour.
- Peak flows varied from a trickle to 0.45 L/s.
- Lag time is a characteristic of each individual lot but is also very dependent on antecedent condition.
- Results indicated that lot grading conditions adjacent to the homes have a significant impact on foundation drain flows.
- The roof flow simulations led to the conclusion that the roof flows generate the majority of foundation drain flows (60 percent). Thirty percent of the rainfall that falls on the house and the dished area around the house, typically

resulting from settled backfill material, enters the weeping tile.

- This study did not address soil characteristics nor did it consider a model for correlation of predicted flows to actual flows.

- Roof contributions to foundation drain flows were very high. Over a longer period, say 24 hours, as much as 50 percent of the total roof volumes is estimated to enter the foundation drains. In addition, it was estimated that 10 percent of the total runoff from entire areas is conveyed to sanitary sewers.

- Homes with proper lot drainage had only 25 percent of the flowrate of a house with poor lot grading.

2.2.2 Ontario

Studies were carried out by the Ontario Ministry of the Environment to assess the quantity and quality of foundation drain water(3). Information was gathered on foundation drain weeping tile flows due to a number of parameters, including:

- Soil type
- Backfill slope
- Weeping tile
- Roof drainage

The study consisted of five residences in Ontario, each equipped with a tipping bucket raingauge on the roof and a pump recorder on a sump pump. Two additional locations, where the apparatus was initially tested, were also analyzed. Technical problems were encountered and as a result not all records are complete. In addition to rainfall-related flows in foundation drains, the effects of snowmelt were examined.

The study notes the following:

- In response to rainfall, a maximum hourly drain flow of 1960 litres was measured.

- In response to rainfall and snowmelt, a daily maximum flow of 13 600 litres was measured.

- Direct relationships between rainfall and foundation flows could not be established.

- The extreme case noted will result in foundation drain flows accounting for 20 percent of yearly sanitary flows in situations where the foundation drain is connected to sanitary sewers. General cases suggest 6 to 10 percent. Even the general case figures have an impact on conveyance and treatment costs.

2.2.3 Milwaukee

As part of an inflow/infiltration (I/I) study, the Milwaukee Metropolitan Sewerage Division (MMSD) carried out an analysis of extraneous flows into sanitary sewers (4).

The on-lot portion of the study used a group of homes along a two-block stretch, as well as homes scattered throughout the rest of the city. Participation by homeowners was voluntary. Each home studied had metering equipment installed to monitor:

- Water consumption

- Flowrates in sewer service connections

- Flowrates from sump pumps connected to foundation drains

If the home selected had no sump pump, one was installed at no cost to the homeowner. Sewer service lateral line repairs, if required, were also carried out at no cost.

Field testing consisted of:

- Rainfall simulations

- Smoke and dye testing of sewer service lines to check for leakage

- Foundation drain flooding using hoses at ground level

The maximum measured flowrates for various time periods indicated large variations. Average rates for 31 sites were:

1-hr	0.10 L/s	(1.6 USgpm)
1-day	0.012 L/s	(280 USgpd)
2-day	0.009 L/s	(210 USgpd)
3-day	0.007 L/s	(150 USgpd)
7-day	0.004 L/s	(100 USgpd)

The maximum recorded 1-day flow rate was 0.064 L/s (1,460 USgpd).

The MMSD study notes the following points:

- The average maximum hourly I/I from sump pumps and foundation drains connected to sanitary sewers was 0.189 L/s (3 USgpm).

- I/I rates observed from sump pumps and foundation drains varied significantly, but homes in clayey type soil and those with positive drainage or in elevated and terraced lots had lower I/I rates.

3.0 EDMONTON TEST PROCEDURE - 1989

A test procedure was developed for simulating severe rainfall events on six lots in Edmonton. The simulations were based on 50-year return period storms. One was a short-duration event of 3 hours and the other was an 8-hour-long duration event. Dry and wet antecedent ground conditions were also investigated.

3.1 Test Sites

The original intent was to carry out four rainfall simulations on each of six sites. It was known that sump pumps had been in limited use throughout Edmonton for a number of years. In addition, since 1988 December, the City of Edmonton has required that foundation drains not be connected to sanitary sewers. As a result, most new homes have been equipped with sump pumps discharging to the ground surface. It was hoped that existing houses in various parts of Edmonton with varying lot grading could be obtained.

Exhaustive efforts were made to locate homes equipped with sump pumps connected to foundation drains. These included:

- Contacts with City of Edmonton departments
  - Building approvals to determine if any new homes would be available
  - Environmental Services, Drainage Maintenance to check if any maintenance crews had records of sump pumps
- Contacts with community league presidents, particularly in areas where sump pumps were thought to exist
- Review of property surveys carried out in I/I studies for Environmental Services

- Word-of-mouth references
- Contacts with various builders and developers

Ultimately, agreement was obtained from five homeowners to carry out the testing. Two houses were in north-central Edmonton and three were in the southeast.

The following table lists various features regarding each house:

SITE	LOCATION	OWNER	AGE OF RESIDENCE
1	North-central	Private individual	7 years
2	Southeast	Builder	Less than 1 year
3	Southeast	Builder	Less than 1 year
4	Southeast	Private individual	Less than 1 year
5	North-central	Private individual	8 years

Figure 1 shows the locations within Edmonton.

3.2 Measurements

The physical attributes of each site were measured. These included:

- Lot dimensions and selected point elevations
- House dimensions
- Sump pump capacity

The summary of the measurements is included in Appendix A. A sample of a lot plan is included as Figure 2. The physical data recorded were needed to calculate the flow-rates required to simulate the design rainfall events and to evaluate the foundation drain flows in response to the simulations.

In addition, two small-diameter boreholes were hand augured by a geotechnical sub-consultant on each lot that was tested. One hole was located within the

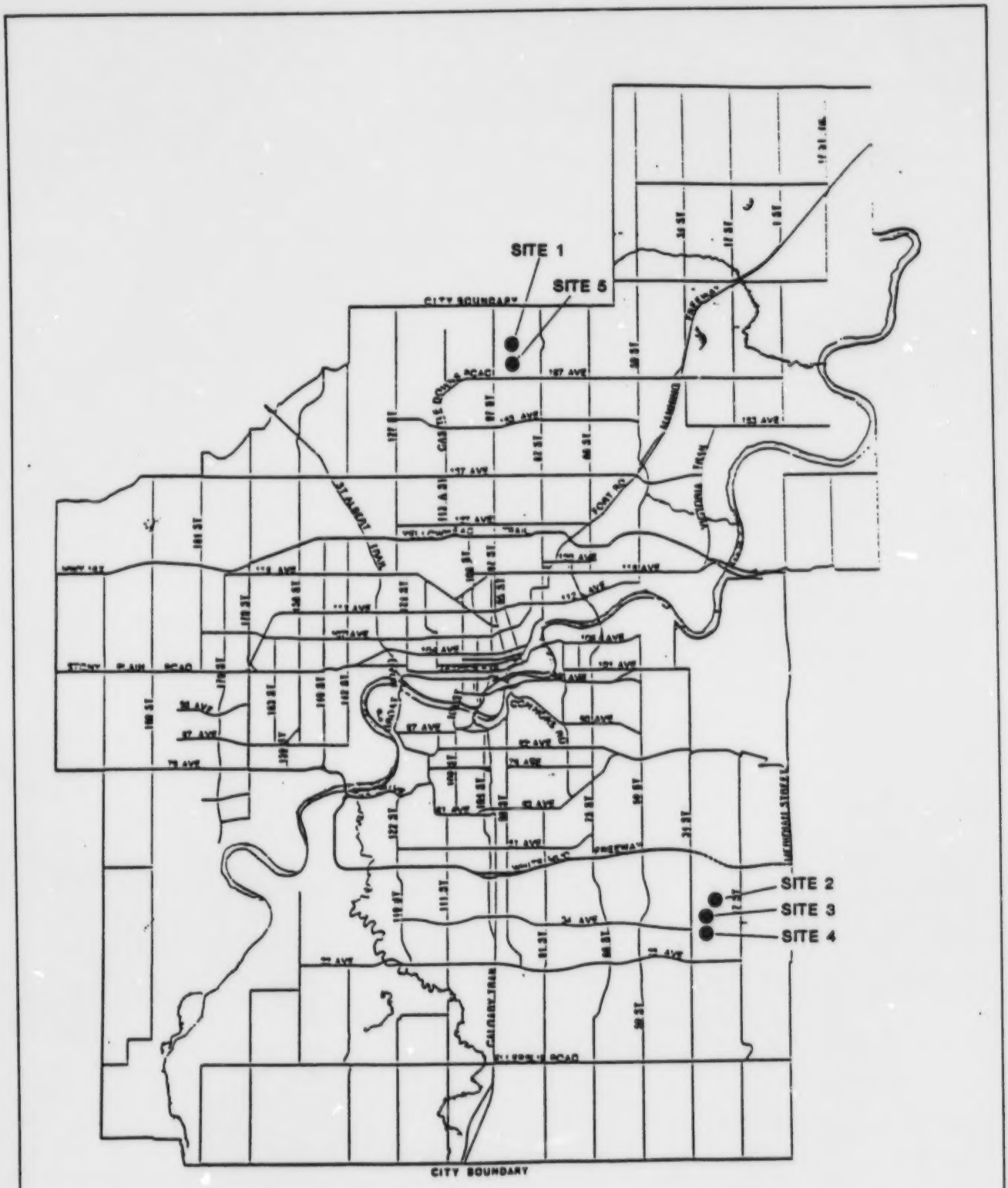

Figure 1
LOCATION PLAN

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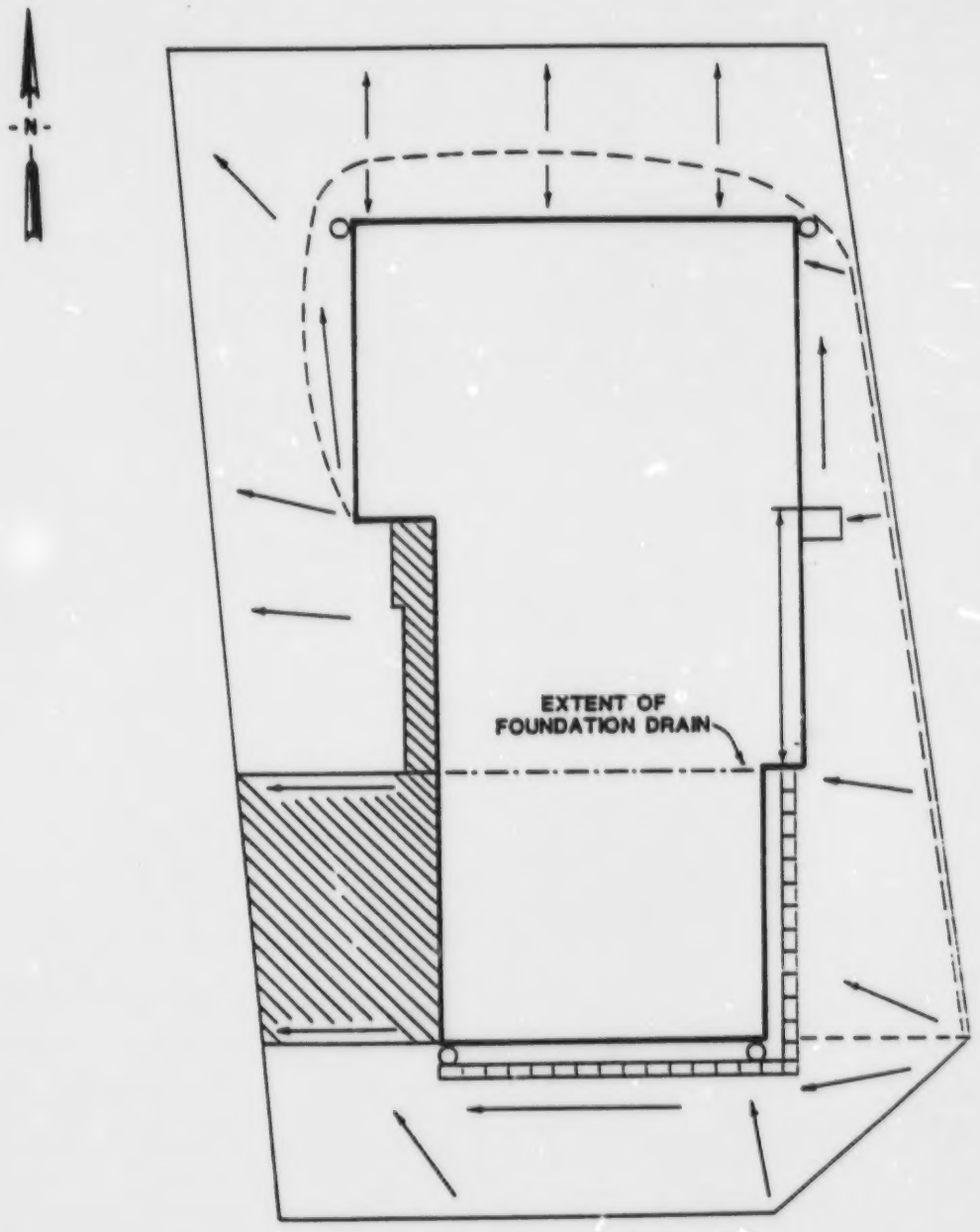

SITE 5
ROOF AREA 261m^2
GROUND AREA 379m^2

DRAINAGE DIRECTION
CONTRIBUTING AREA
DOWNSPOUT

Figure 2
LOT PLAN

CH2M HILL

backfill zone of the house and the other in supposed native material.

Soil moisture contents were calculated for the depths in each hole and the soil visually classified. Based on this data, the permeability of the soils was estimated. Permeability is a soil property which describes how water flows through soil and is expressed as a velocity.

3.3 Equipment

The following equipment was required to carry out the simulations:

- Totalizing flow meter installed at the fire hydrant which provided the water. The meter recorded volumes to an accuracy of 0.01 m^3.
- Standard fire hoses to deliver flows to the manifolds
- Gate valves at the hydrant and at each manifold
- Two manifolds to split and control the flows. One manifold had two branches to direct flows to both the lot and roof leaders. The other manifold had only one branch and was used to provide lot flows only. Each branch was equipped with a rate-of-flow meter.
- Soaker hoses to apply water to the lot areas and solid walled garden hoses to simulate roof leader flows
- Current sensors and dataloggers connected to each sump pump

The City of Edmonton Environmental Services provided all the equipment required to apply the water and record flows.

In addition, natural precipitation data were made available from Environmental Services.

Figure 3 provides a schematic representation of the test apparatus.

3.4 Problems Encountered

This study was ultimately successful, but a number of problems were encountered during the course of the work. These included:

- Many potential sites were located but in some cases homeowners were unwilling to participate. In other cases, the foundation drains were indirectly connected to sumps via gravel drains or through basement gravels.

- Equipment procurement delayed the field program start from May to late July. The rate-of-flow meters and current sensors are specialized items and the delivery period was longer than anticipated.

- Personnel familiarization with equipment resulted in some delays and data collection errors. These problems diminished as the program progressed.

- Malfunctions with sump pumps resulted in lost data for some simulations. Pump controller problems at two sites resulted in extended pump running times. These records did not provide accurate data.

- The test procedure produced some inconveniences for homeowners. To minimize discomfort, at two private residences the sidewalks and driveways were not irrigated.

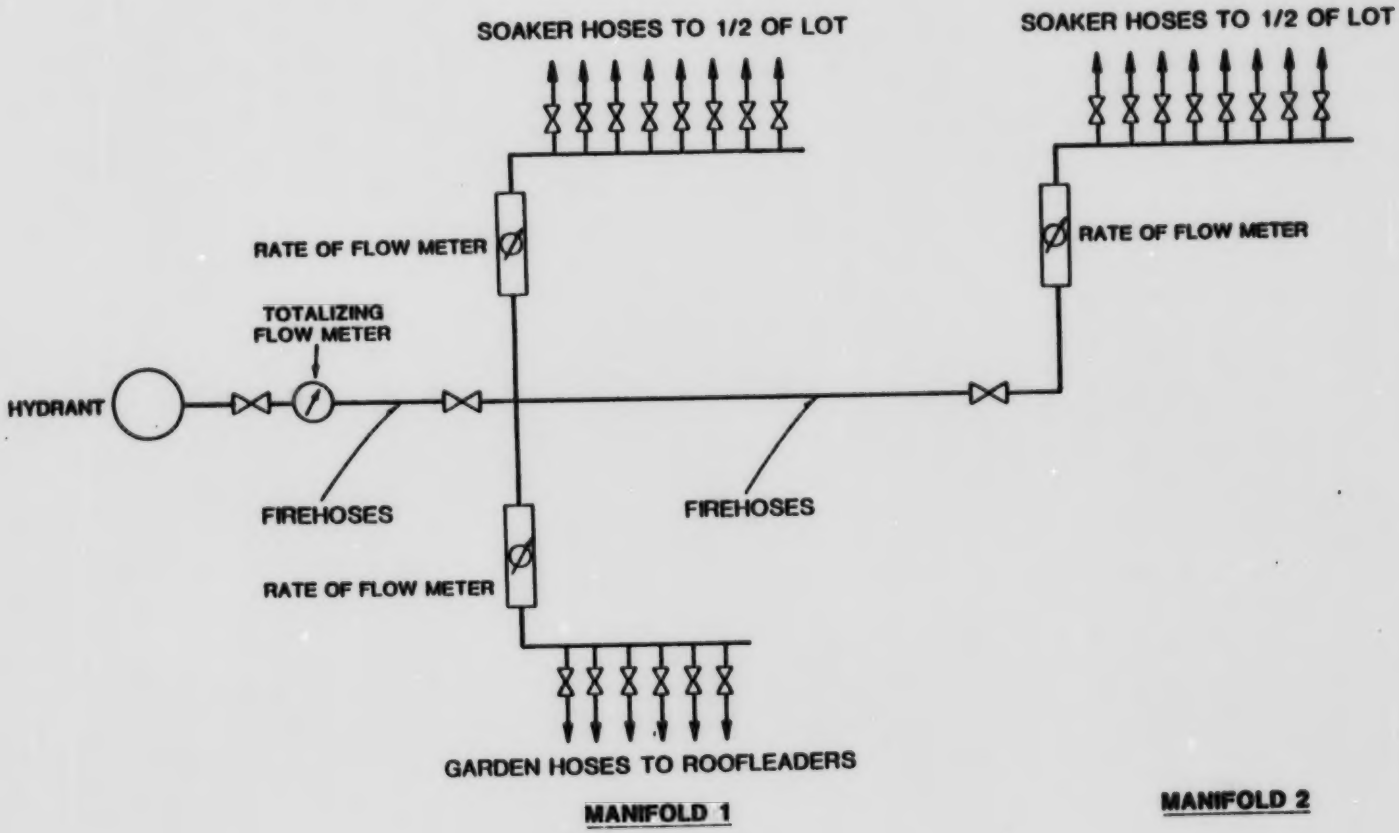

Figure 3
SCHEMATIC PLAN OF
TYPICAL RAINFALL SIMULATION LAYOUT

CH2MHILL

4.0 SIMULATION RESULTS

The sump pump records were downloaded from the dataloggers in a raw form. The data were translated using the datalogger manufacturer's software. The information recorded was the actual pump running time on a 1-second basis.

The translated data were converted to identify pump start and stop times. This information was used to calculate the pump cycle time and the pump running time, both of which were required to calculate the pumped volume and inflow rate.

Figure 4 is a sample of the calculated total inflow rates for the tests carried out at Site 5. It must be noted that these values are derived from actual pump records and, therefore, include baseflow components. The plot shows that in some cases the inflow rate resulting from a test had not returned to baseflow values prior to starting the next simulation.

Each simulation was analyzed and an inflow hydrograph developed. The tail effect was estimated if another simulation commenced before inflows reached baseflow values. Response hydrographs were developed for each simulation by deducting the baseflows. Sample response hydrographs for Site 5 are shown on Figures 5 to 8.

Each response by hydrograph has two vertical scales.

- On the left side of the graph the scale shows the inflow in litres per second.
- On the right side, the scale shows precipitation intensity in mm per hour.

The inflow rate is plotted as a line on the graph and the precipitation is shown as a shaded area at the top of the graph, indicating the intensity and duration of precipitation.

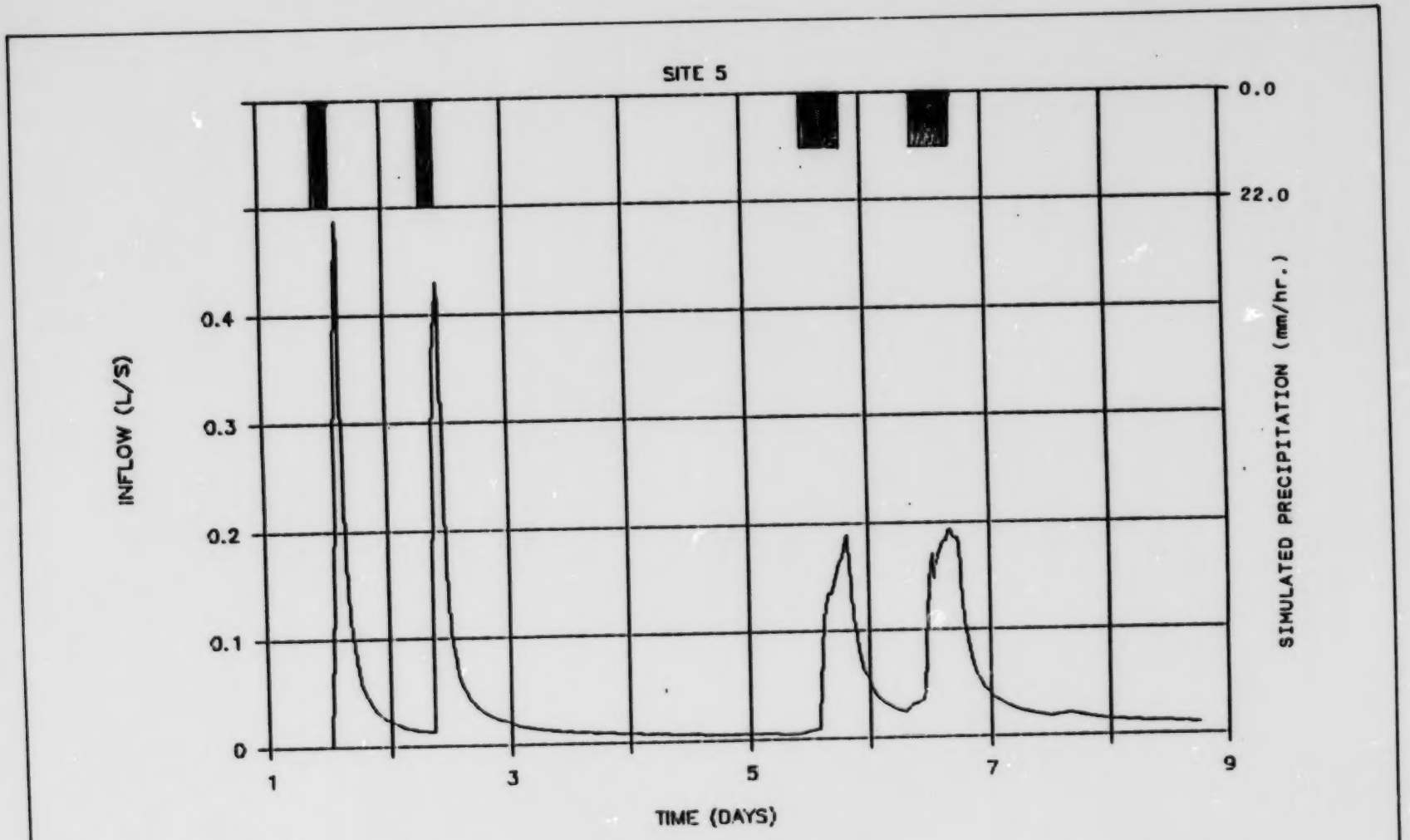

Figure 4
TEST PROGRAM RESPONSE

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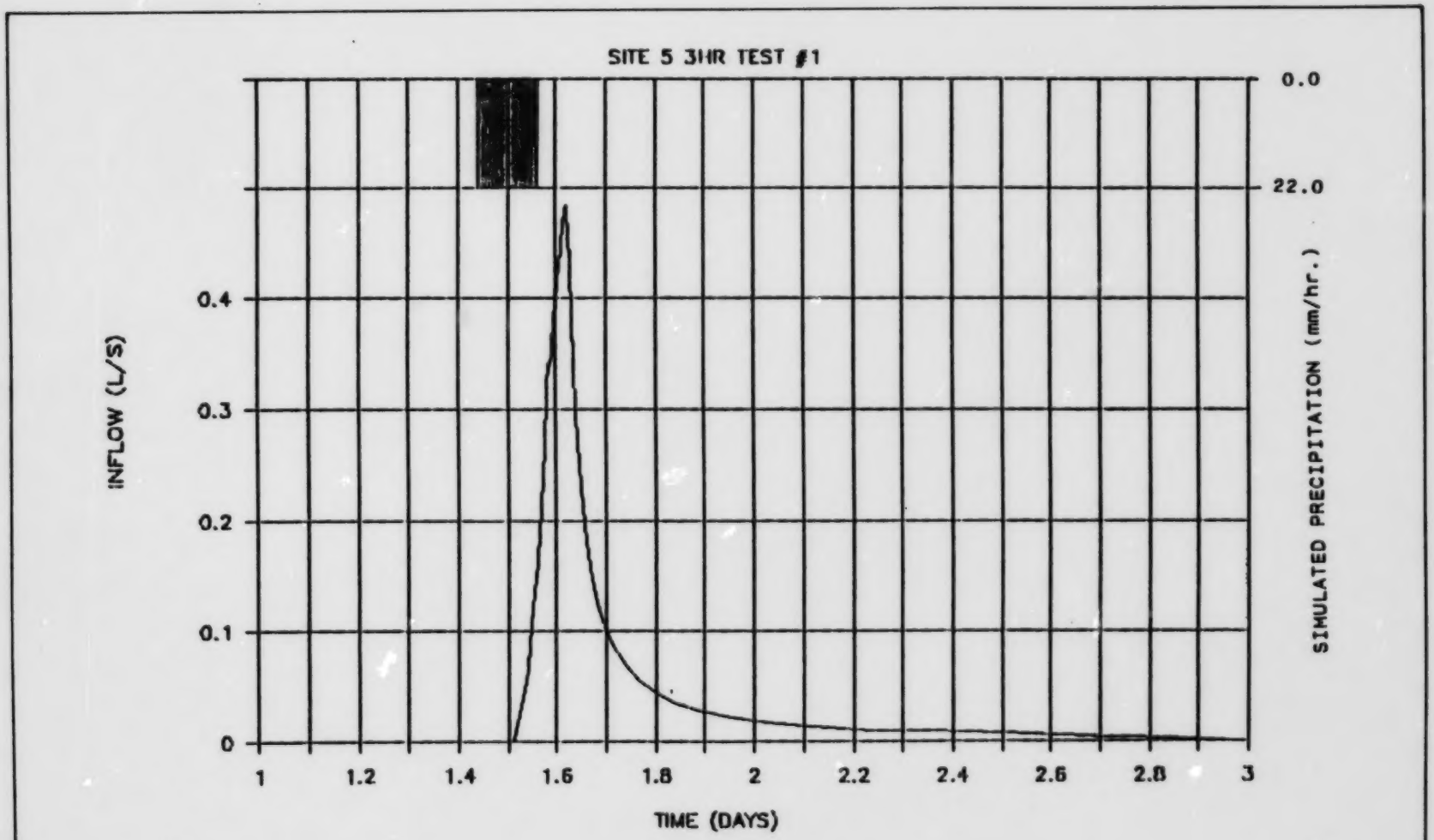

Figure 5
3-HOUR TEST RESPONSE

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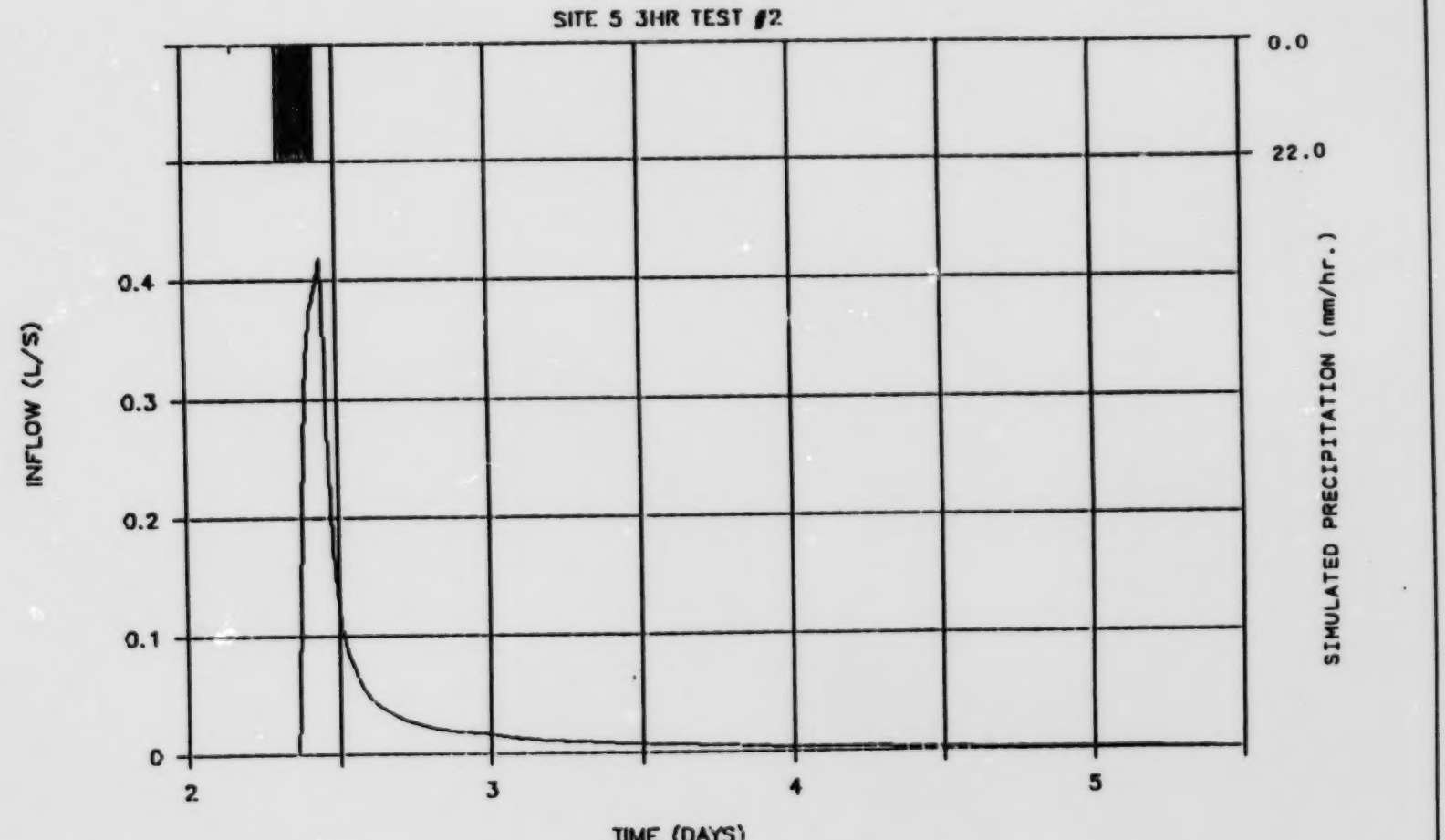

Figure 6
3-HOUR TEST RESPONSE

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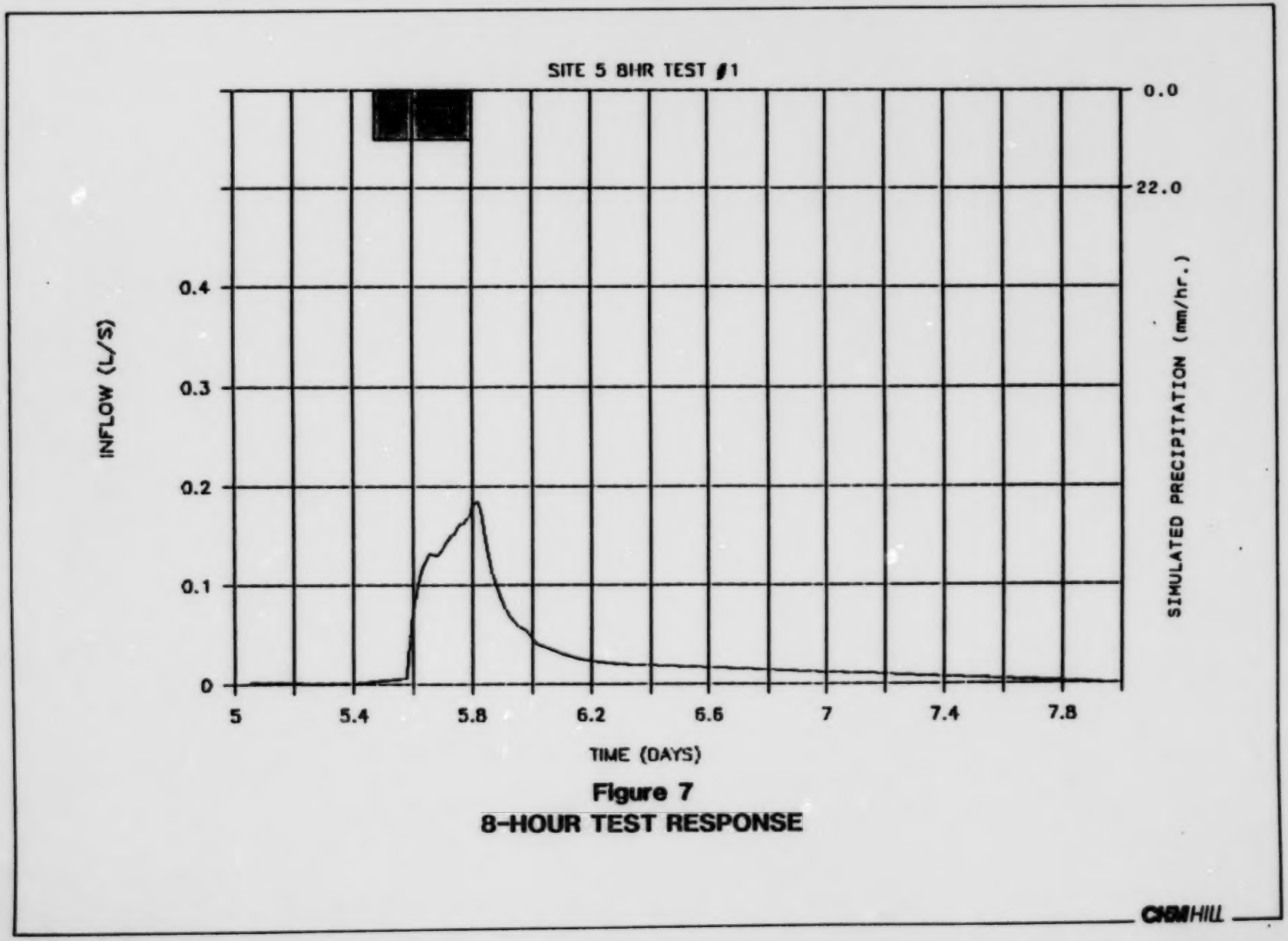

Figure 7
8-HOUR TEST RESPONSE

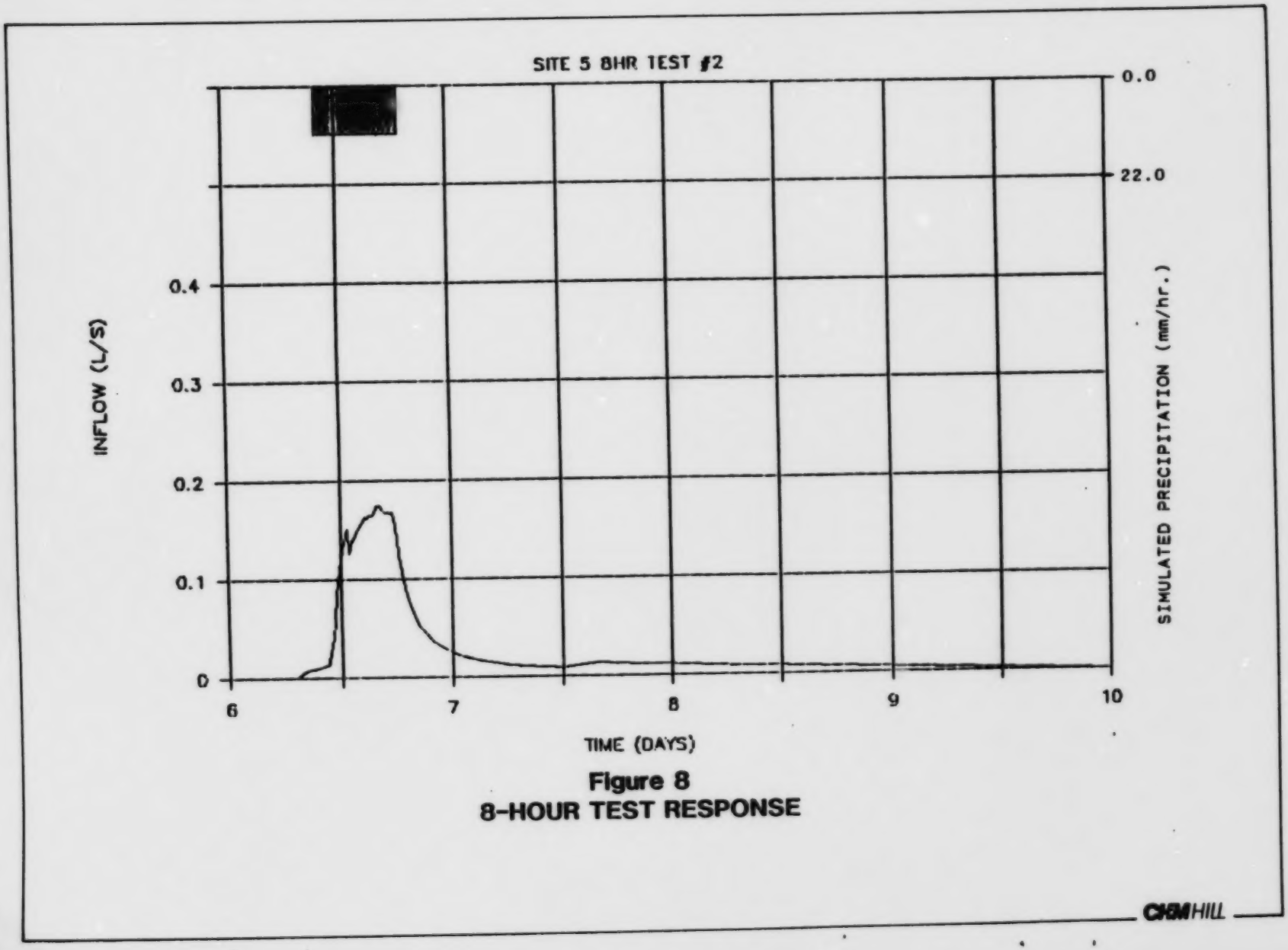

Figure 8
8-HOUR TEST RESPONSE

The response hydrographs were used to calculate the total volume of water entering the foundation drains in response to the individual simulations.

The total inflow and response hydrographs for the other sites are included in Appendix A.

A summary of the simulations follows in Table 1.

The column titled "Peak Recorded Inflow" lists the peak flows calculated using the pump records. These values include baseflows. The flows listed for Site 5 can be seen on Figure 4.

The column titled "Peak Response Inflow" lists the peak response flows with baseflows deducted. The flows listed for Site 5 can be seen on Figures 5 to 8.

4.1 Discussion of Results

The recorded responses to individual simulations varied considerably from site to site as well as from simulation to simulation. The volume of simulated precipitation entering the foundation drains ranged from 6.4 percent to 36.6 percent. The peak recorded flows ranged from 0.07 L/s to 0.49 L/s.

It was expected that flows resulting from wet antecedent condition simulations would be higher than those resulting from dry tests. It was also anticipated that the short duration tests would result in higher peak flows and that the long duration simulations would produce greater percentages entering the foundation drains. In general, none of these expectations was observed. A review of the results as presented in Table 1 follows:

- Site 1 - The 3-hour simulation did produce higher flows than the 8-hour, but it also produced a higher percentage of precipitation entering. Mechanical malfunctions with the sump pump controller affected the other simulations.

Table 1
SUMMARY OF SIMULATIONS

Site	Date	Simulation	Start Time	Volume Applied (m^3)	Intensity Applied (mm/h)	Peak Recorded Inflow (L/s)	Peak Response Inflow (L/s)	% Entering Foundation Drain
1	Jul 22	3-hr wet	10:00	45.32	20.3	0.42	0.41	15.6
	Aug 8	8-hr dry	10:45	68.50	11.6	N/A	N/A	N/A[1]
	Aug 9	8-hr wet	08:50	71.64	12.1	N/A	N/A	N/A[1]
	Aug 29	3-hr dry	12:35	51.42	23.0	N/A	N/A	N/A[1]
	Aug 30	8-hr wet	10:10	68.86	11.7	0.21	0.20	12.8
2	Jul 27	3-hr dry	11:50	45.20	23.0	N/A	N/A	N/A[2]
	Jul 28	3-hr wet	11:40	45.93	23.0	0.07	0.07	7.7
	Aug 3	8-hr dry	09:20	59.40	11.3	0.08	0.08	7.0
	Aug 4	8-hr wet	08:55	61.12	11.7	0.18	0.16	11.1
	Aug 10	3-hr dry	08:25	45.96	23.4	0.09	0.09	7.3
	Aug 31	3-hr-leaders next to house	11:55	45.99	23.4	0.01	0.01	N/A[3]
	Sept 5	3-hr no roof flows & no ppt within 1.5 m of house	10:35	25.01	22.0	0.002	0.002	N/A[3]
3	Aug 18	3-hr wet	11:25	41.60	24.7	0.16	0.15	6.4
	Aug 21	3-hr dry	11:05	40.47	24.0	0.12	0.12	7.4
	Aug 22	8-hr wet	08:15	52.12	11.6	0.13	0.12	7.9
	Aug 31	3-hr no roof leaders	10:15	32.28	27.3	0.14	0.14	8.6
	Sept 5	8-hr dry	08:52	48.71	10.9	N/A	N/A	N/A[4]
	Sept 6	3-hr roof leaders only	10:21	11:16	22.3	0.28	0.27	36.6
4	Aug 17	3-hr dry	12:00	44.52	24.7	0.09	0.07	15.7
	Aug 18	3-hr wet	10:15	45.02	25.0	0.30	0.25	27.3
	Aug 21	8-hr dry	10:00	60.50	12.6	0.15	0.11	16.0
	Aug 22	8-hr wet	07:10	60.32	12.6	0.15	0.11	14.7
5	Aug 24	3-hr dry	10:40	43.21	22.5	0.49	0.48	11.9
	Aug 25	3-hr wet	07:35	42.61	22.5	0.43	0.42	12.9
	Aug 28	8-hr dry	11:25	58.16	11.4	0.19	0.18	10.9
	Aug 29	8-hr wet	09:30	57.74	11.3	0.19	0.17	11.4

Notes:

1. Pump controller failure resulted in recurring extended pumping time.
2. Datalogger was not set properly.
3. Response was extremely low compared to previous, indicating change in system characteristics.
4. Pump controller failure resulted in extended pumping time and datalogger overloading.

- Site 2 - The 3-hour simulations originally planned did not produce the expected results. The dry test produced slightly higher flows, but the wet test resulted in a slightly greater volume entering. The wet 8-hour test did produce higher flows and greater volumes entering than did the 8-hour dry simulation. The two additional 3-hour simulations, one with roof leaders discharging close to the house and one with no roof leader flows as well as no water applied within 1.5 m of the house, did not produce a notable increase in flows above base flows. It is suspected that this is due to a change in the foundation drain flow characteristics brought about for unknown reasons.

- Site 3 - The two originally designated 3-hour simulations produced the expected result in peak flows, but in the dry simulation a higher percentage entered. The 8-hour wet test produced relatively high flows and a greater percentage entering than the 3-hour simulations. Two additional 3-hour tests were carried out. The simulation without roof leaders produced flows similar to the normal 3-hour tests and a higher percentage entering. The simulation with only roof leaders discharging close to the walls produced very high flowrates and the highest recorded percentage entering.

- Site 4 - The 3-hour simulations produced the expected flow and percentage relationships but the difference is abnormally large. The 8-hour tests resulted in similar peak flowrates but the dry test produced a higher percentage entering.

- Site 5 - The 3-hour simulations produced flows much higher than did the 8-hour tests. The short duration tests also produced higher percentages entering the foundation drain. During the first simulation carried out, one window well filled with water. To prevent this reoccurrence, the irrigation pattern was varied during the rest of the tests.

The average peak response inflow for 19 simulations tabulated can be as follows:

- Average response for 19 simulations — 0.19 L/s
- Average response for 3-hour tests — 0.233 L/s
- Average response for 8-hour tests — 0.141 L/s
- Average response to all tests

Site 1	0.30 L/s
Site 2	0.10 L/s
Site 3	0.16 L/s
Site 4	0.14 L/s
Site 5	0.31 L/s

The following observations can be made from the simulation records:

- On average, the highest inflow rates resulted from the short-duration, high-intensity simulations.

- No definite pattern emerges regarding antecedent conditions. That is, there is no consistency as far as wet condition peak flows being higher than dry condition ones. It is possible that the soils could swell during or after a dry simulation and close off fissures or cracks that conduct water to the foundation drains.

- The permeabilities visually estimated in the study do not appear to be indicative of those in the backfill zone. This is likely due to cracks or fissures or voids in the backfill. Other tests are necessary to determine more accurate permeabilities.

- It is difficult to determine the effect of lot grading on the foundation drain response rate. Site 5 had the highest percentage of lot area poorly graded and it also had the highest average peak flows. On the other hand, Site 1

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had the lowest percentage of lot area poorly graded, but it showed the second highest response.

Although no firm, fixed pattern can be established, the recorded flowrates and volumes pumped as result of the simulations are substantial. As a comparison, consider sanitary sewer flows designed on the following basis:

- 1,000 single family units
- 3.2 people/unit
- 380 L/d/capita water consumption
- 3.4 as a peak flow factor, based on Harmon's formula

The average daily design flows would be 0.014 L/s/house and the peak design flows would be 0.048 L/s/house. Note that these flows do not include any infiltration or inflow allowances. The design sanitary flows are lower than all the flows resulting from the simulations. Foundation drain flows have the potential to cause sanitary sewer system overloading.

5.0 MODELING OF FOUNDATION DRAIN FLOWS

A foundation drain flow model was previously developed by CH2M HILL. The application of various input parameters and resulting predicted flows are discussed below. Figure 9 illustrates some of the model parameters.

5.1 Application of the Model

The K factor is based on soil characteristics. In this study values of K in the backfill zone were estimated by a geotechnical consultant. In general, the values ranged from 10^{-4} - 10^{-8} cm/s with the exception of Site 4 where sand backfill was encountered. The K was estimated at 10^{-2} - 10^{-4} cm/s at that site.

A K of 10^{-3} cm/s was used in the model to account for flow through fissures in the backfill and along the foundation wall. This was considered appropriate as a "bulk" permeability factor.

The normal roof leader discharge locations were 1.5 m away from the house at all sites. The normal C value for roof runoff is 0.9.

In the modeling carried out, it was assumed that 10 percent of roof flows contributed to foundation drain flows.

The C value for lot runoff varied for each site. The actual volume entering is used in conjunction with the area assumed to contribute to foundation drain flows to calculate C. Areas considered to be contributors were those grading towards the house, as well as the backfill zone. The lot C value was the ratio of flow entering the foundation drain and the amount of precipitation applied to the contributing area.

The recorded simulation intensities for each test were used in the model.

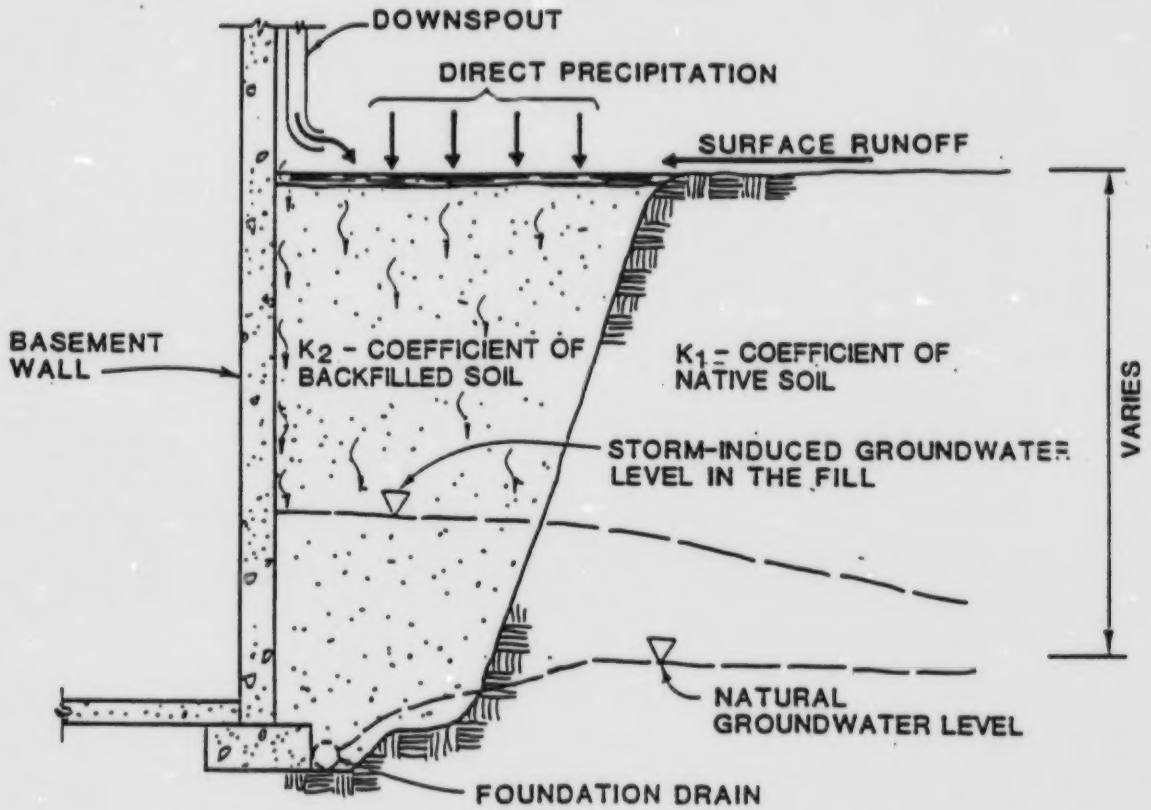

Figure 9
MODEL PARAMETERS

CH2M HILL

5.2 Model Results

A model simulation was carried out for each test that produced reasonable results. Table 2 compares the modeled and observed peak flowrates.

The ratios of comparisons in Table 2 illustrate the variations in the modeled and actual flows. The same K value is used in all the model runs. With the exception of Site 4, each site shows some ratios with good correlation between the model and recorded results. It is not feasible to vary the K value for individual runs on the same site.

The results from the model could be modified by adjusting various parameters within the model. However, the actual data recorded did not provide a basis for adjusting or modifying parameters within the model to produce better correlation with observed results.

Further work is required to gather information that would provide measured or calculated data to permit variation of model parameters.

Table 2
COMPARISON OF MODELED TO RECORDED FLOWS

Site	Simulation	Peak Recorded Inflow (L/s)	Model Results (L/s)	Ratio of Recorded to Model Results
1	3-hr wet	0.42	0.36	1.167
	8-hr wet	0.21	0.27	0.778
2	3-hr wet	0.07	0.19	0.368
	8-hr dry	0.08	0.13	0.615
	8-hr wet	0.18	0.22	0.818
	3-hr dry	0.09	0.19	0.474
3	3-hr wet	0.16	0.20	0.800
	3-hr dry	0.12	0.21	0.571
	8-hr wet	0.13	0.13	1.000
	3-hr, no roof leaders	0.14	0.15	0.933
	3-hr, roof leaders only	0.28	0.22	1.273
4	3-hr dry	0.09	0.36	0.250
	3-hr wet	0.30	0.58	0.517
	8-hr dry	0.15	0.30	0.500
	8-hr wet	0.15	0.27	0.556
5	3-hr dry	0.49	0.26	1.885
	3-hr wet	0.43	0.28	1.596
	8-hr dry	0.19	0.20	0.950
	8-hr wet	0.19	0.20	0.950

6.0 CONCLUSIONS

The results of this study confirm the significance of foundation drain contributions to sanitary or storm sewer systems. Many areas experience sanitary sewer system surcharging and/or basement flooding as a result of rainstorms.

6.1 Design Flows

Under normal conditions a sanitary sewer system should not have to be designed on the basis of a storm return period. This has, however, been the case in several recent rehabilitation projects in Edmonton. Based on this study and the findings of several I/I studies, it appears that foundation drains can be a major contributor to storm-related flows in sanitary sewers.

Sufficient allowances must be made in the design of sewer systems if foundation drain flows are to be permitted to be connected. Until recently, the design allowance for Edmonton has been 0.06 L/s. The average peak flowrate of 0.19 L/s for the simulations is similar to values currently used in sanitary sewer rehabilitation design in Edmonton.

The results of this study show that the foundation drain flows in direct response to a 50-year return storm vary from 0.07 L/s to 0.49 L/s. This range is significantly higher than design allowances for foundation drain contributions to sanitary sewers currently used by some municipalities. The recorded flows do, however, vary considerably within a small geographical area, even for homes with similar grading. The substantial variation in recorded peak flowrates does not justify recommending a fixed design value. Further study may provide a basis for determining a sound value.

It is interesting to observe the results at roof-leader-only flows which discharge close to the foundation wall. It has been suspected that roof leader flows are the most significant contribution to

foundation drain flows. The peak response (0.28 L/s) to the roof-leader-flow-only test at Site 3 is considerably higher than in the other simulations carried out at this site which, in this case, confirms significant roof leader contribution to foundation drain flows when the discharge is close to the house. This emphasizes the need for proper roof leader discharge practice, as well as proper lot grading to direct this source as well as precipitation runoff away from the home.

6.2 Discharge Alternatives

There are four currently used discharge alternatives that could be considered for foundation drain flows:

1) Sanitary sewers
2) Storm sewers
3) Sump pump
4) A fourth, known as the third-line system, is used by some municipalities.

The sanitary sewer option has been most common over recent years. It has become obvious in some cases that the contributions from foundation drains are causing overloading in response to storm events. The historical design allowances have typically been less than current observations would suggest. As a result, other discharge alternatives are being considered.

The storm sewer systems have been the next most common discharge site for foundation drains. This alternative is complicated by number of factors or parameters that must be considered. The storm sewer system must be designed to convey the foundation drain flows as well as to ensure that for a given level of service, there should be no surcharge above the basement floor level. This leads to the question of what level of service and what freeboard should be provided. Storm sewers are typically designed to convey a 1-in-2-year to 1-in-5-year return period

storm without surcharging. For higher return periods the storm sewers surcharge and can overflow into the major, overland drainage system.

Two main reasons exist for not connecting foundation drains to storm sewers:

- Storm sewers do not typically extend to all reaches within a subdivision.
- Storm sewers are often not deep enough to allow a gravity connection to foundation drains.

In the past few years sump pumps have become increasingly common as a foundation drain discharge. This system removes the requirements for sufficient sewer system capacity. It does, however, place the responsibility on the homeowner to ensure that the system is operating properly. The sump and pump must be appropriately sized. The discharge location must be such that the water does not recycle to the foundation drain. The discharge has been observed to cause problems with saturated, mushy lawns in the summer and ice buildup in the winter.

The third-line system has been discussed in some municipalities. The theory is that there would be a third sewer system which would be dedicated to foundation drain discharges. It would typically be smaller in diameter than a storm sewer and near the elevation of the sanitary sewer to ensure gravity connection. It would discharge to the same areas as the storm sewers. This is likely the most costly method of those discussed here.

6.3 Sump Capacity, Size, and Discharge

As previously mentioned, the sump and pump must be properly selected to adequately serve each installation. As this study has illustrated, there can be considerable variability in expected foundation drain inflow rates. There are a number of considerations in designing sumps and selecting pumps.

The sump and pump must be designed together, not individually, to ensure that the pump can convey the expected inflow in an efficient manner. Of particular concern is excessive pump cycling, which can cause mechanical problems. The sump must, therefore, be sized to store a volume of water that the pump can discharge in a reasonably short time period.

The discharge should be such that it creates no problems. In this study three discharge alternatives were observed:

- Discharge above-ground at house foundation onto a splash pad
- Discharge above-ground, removed from the house area via hose
- Discharge below ground with discharge flows surfacing at some distance away from house

There are advantages and disadvantages in all the discharge alternatives. For example, the splash pad discharge may not direct the water far enough away from the house and the hose option could result in frozen lines in the winter, as could the below-ground discharge.

The two homeowners who discharged away from the house using a flexible hose got the benefit of watering the lawn using free water.

6.4 Further Study

Many questions regarding foundation drain flows and sump pump installation remain unanswered. This study provided many useful observations and benefits with respect to the response of foundation drain flows to simulated severe rainfall events.

Many factors in this study were, however, uncontrollable or unobservable. These include:

- Lot grading
- Backfill practice
- Foundation drain installation practice
- Sump orientation
- Groundwater level response

It would be useful to isolate some or all of these factors and others in a somewhat more controlled environment to analyze their roles and develop a better understanding of the parameters involved in foundation drainage.

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2. "Investigation into the Phenomenon of Weeping Tile Flows in Suburban Winnipeg Homes." R. Heino. Internal City of Winnipeg Report. September 1972.

3. "Quantity and Quality of Weeping Tile Flow." Maria Schouten. Ministry of the Environment, Ontario. May 1972.

4. "Private Property Infiltration/Inflow Pilot Project, Summary Report." Milwaukee Metropolitan Sewerage District. Milwaukee Water Pollution Abatement Program. August 1981.

Appendix A
SITE DATA AND RESPONSE HYDROGRAPHS

SITE 1

Five simulations are recorded for Site 1. One additional simulation was carried out on 1989 July 21. The required flows were not achieved and the simulation was aborted.

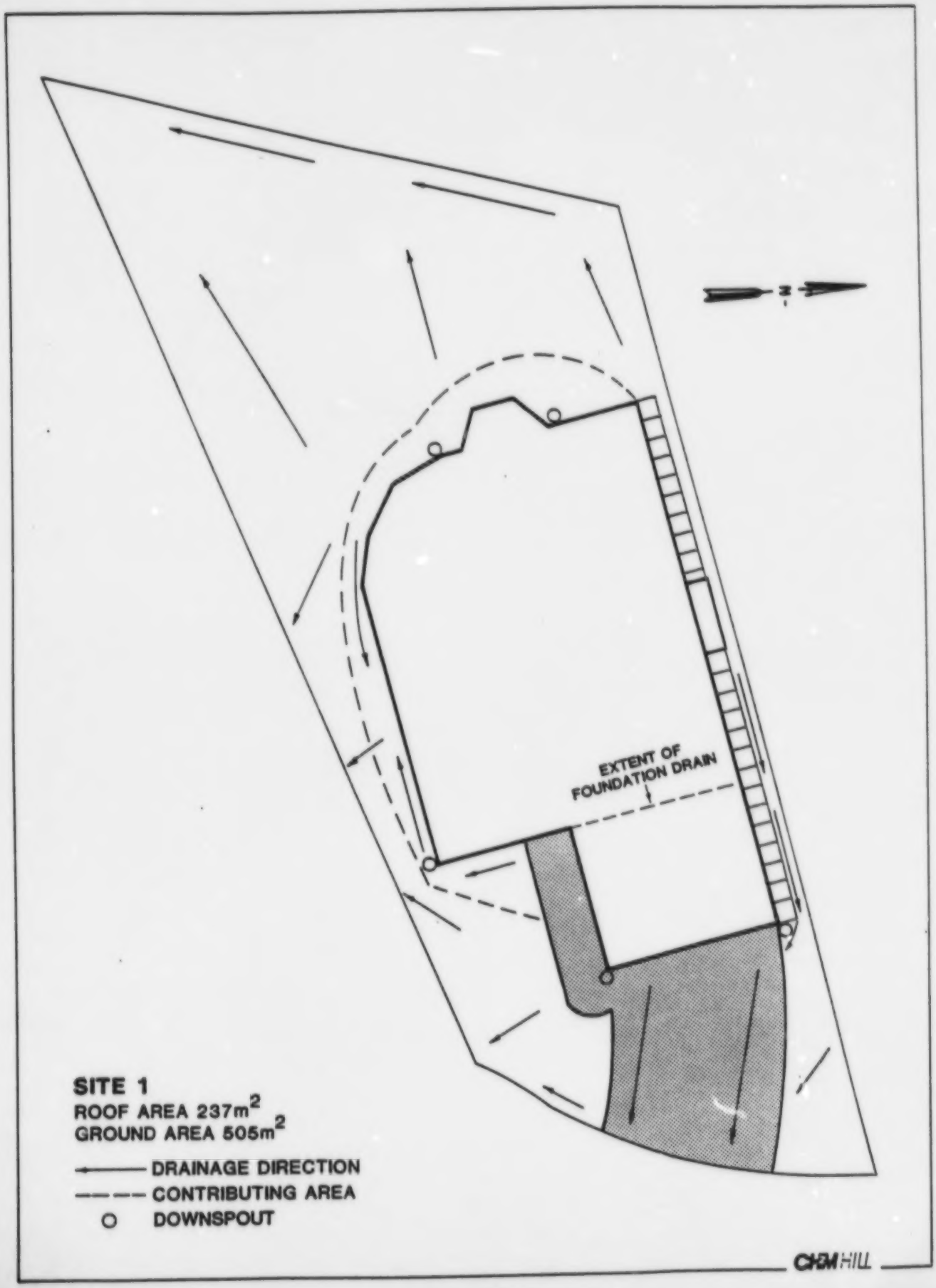
The data collected in the next three simulations were not usable. A pump controller malfunction resulted in extended periods of pumping. Once the problem was determined, it was rectified and the final simulation provided good data.

Site Data Summary

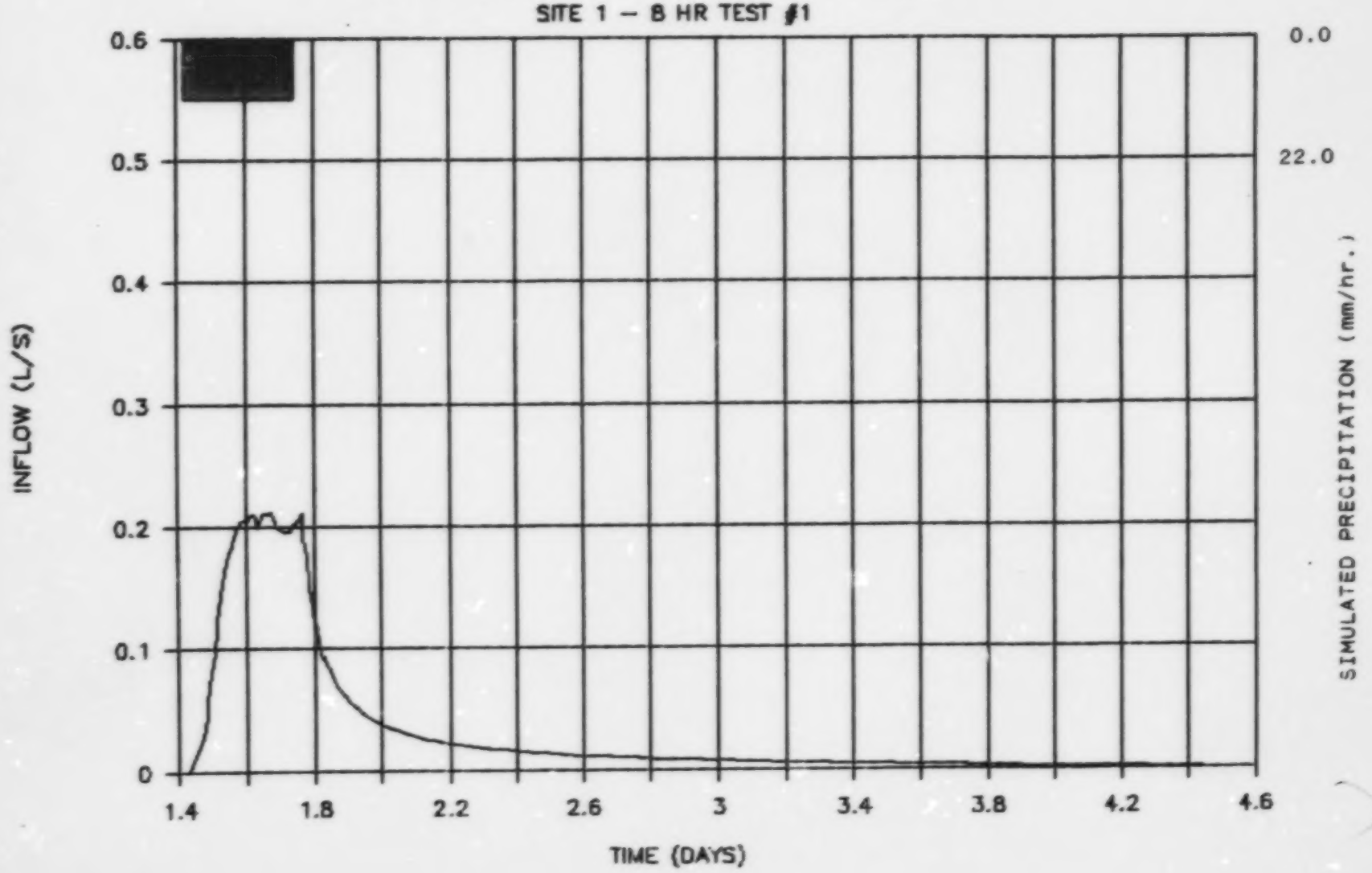
Roof area - 237 m^2
Lot area - 505 m^2
Lot area contributing to foundation drain flow - 46.5 m^2
Pump rate:

1. Old pump - 0.72 L/s, based on discharge measurement

2. New pump - 0.65 L/s, based on sump drawdown


EXTENT OF
FOUNDATION DRAIN
SITE 1
ROOF AREA 237m2
GROUND AREA 505m2
DRAINAGE DIRECTION
CONTRIBUTING AREA
DOWNSPOUT
CHEMHILL

8 HR TEST RESPONSE



SITE 2

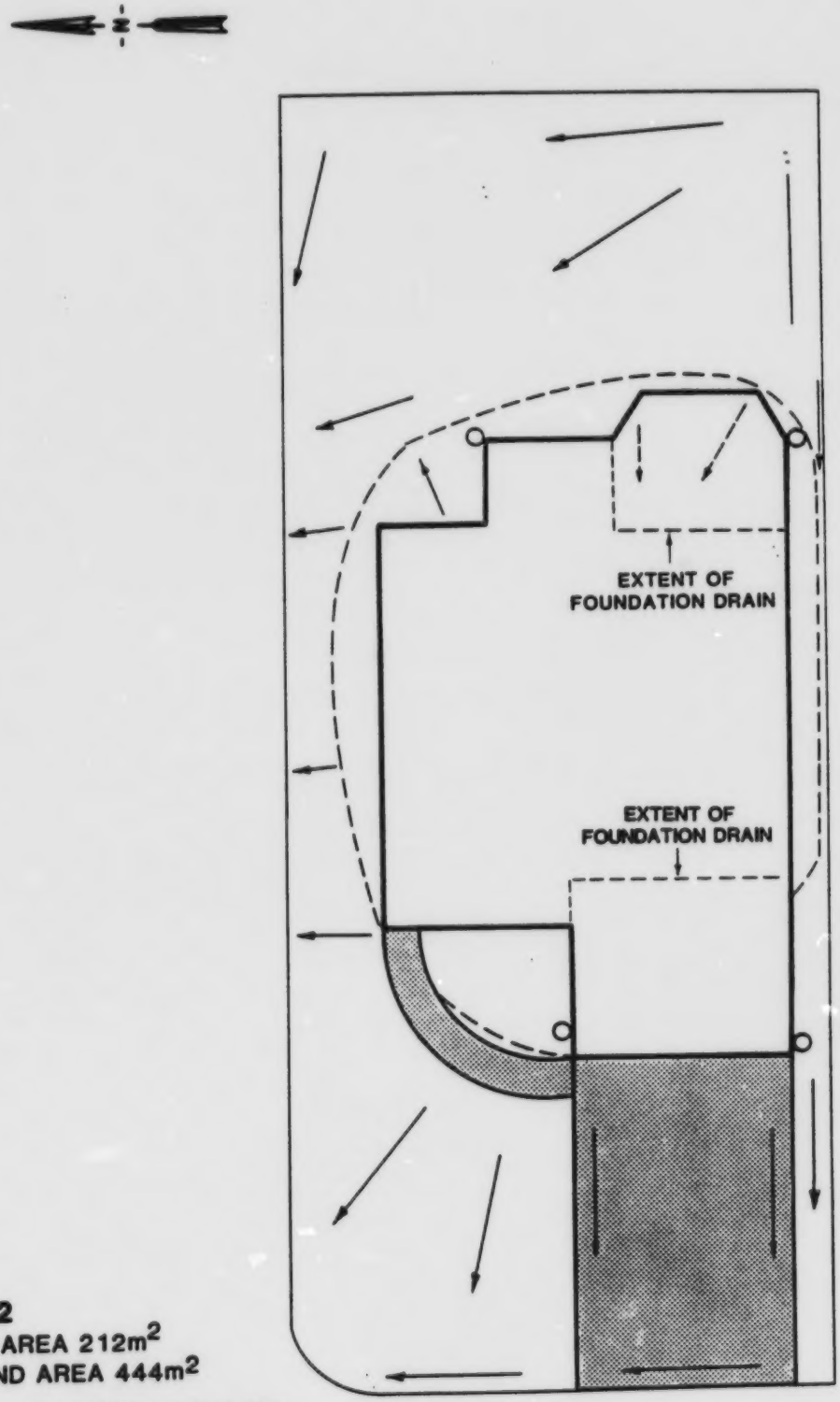
Seven simulations were carried out on Site 2. During the first one, the datalogger was not set up properly. As a result, there were no pump data collected. The next four simulations were those originally planned. The last two simulations were carried out to partially replace simulations not possible at a sixth site and were variations that simulated:

- Normal 3-hour test but roof leaders discharging next to house
- 3-hour test but no roof leaders and no precipitation applied within 1.5 m of house (to simulate an impermeable barrier)

The foundation drain characteristics appeared to have changed prior to the last two simulations as no appreciable increase was noted in either test.

Site Data Summary

Roof area - 212 m^2
Lot area - 444 m^2
Lot area contributing to foundation drain flows - 82 m^2
Pump rate - 1.05, based on discharge measurements

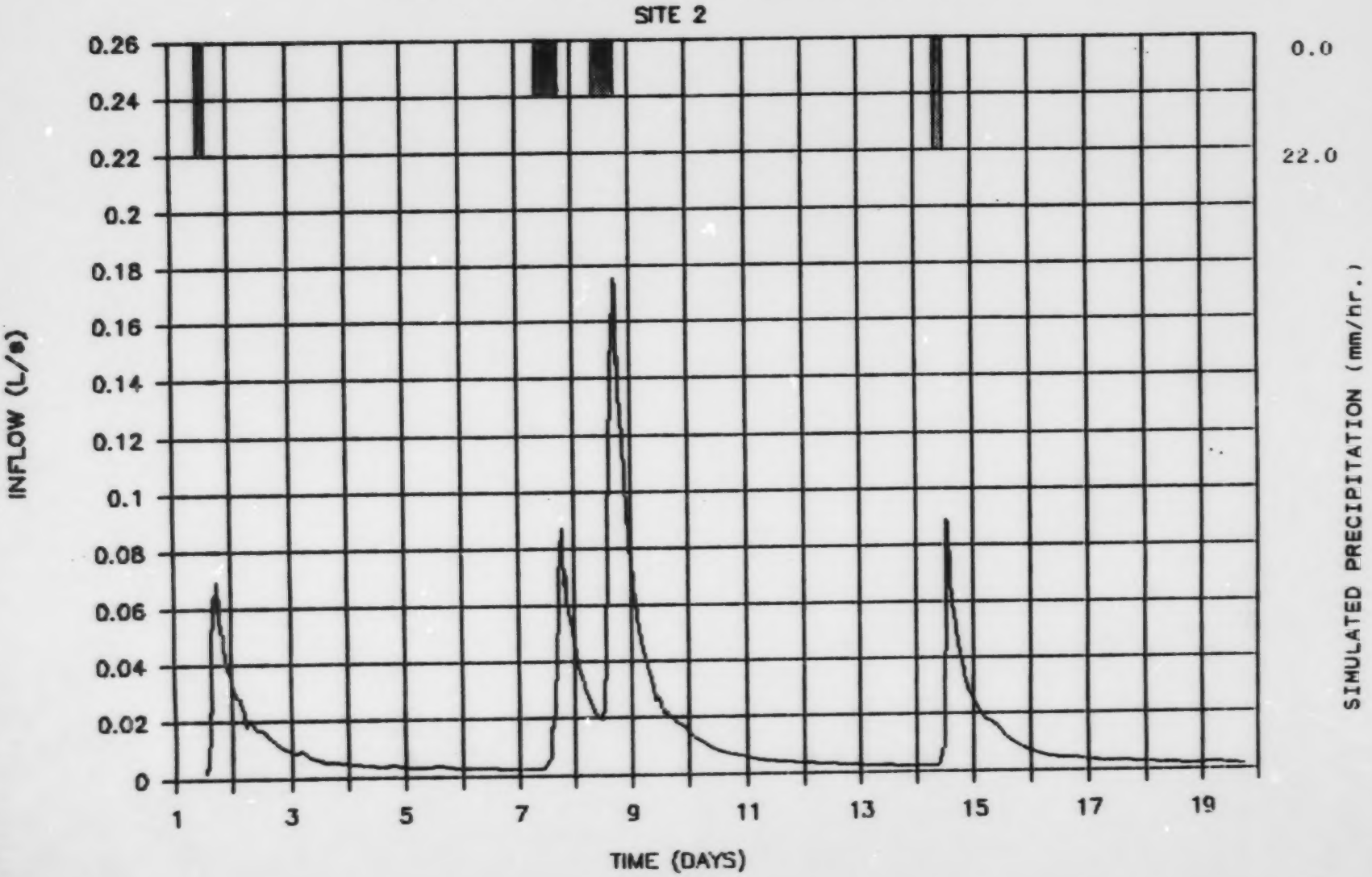


SITE 2
ROOF AREA 212m^2
GROUND AREA 444m^2

←—— DRAINAGE DIRECTION
- - - - CONTRIBUTING AREA
○ DOWNSPOUT

CH2M HILL

TEST PROGRAM RESPONSE



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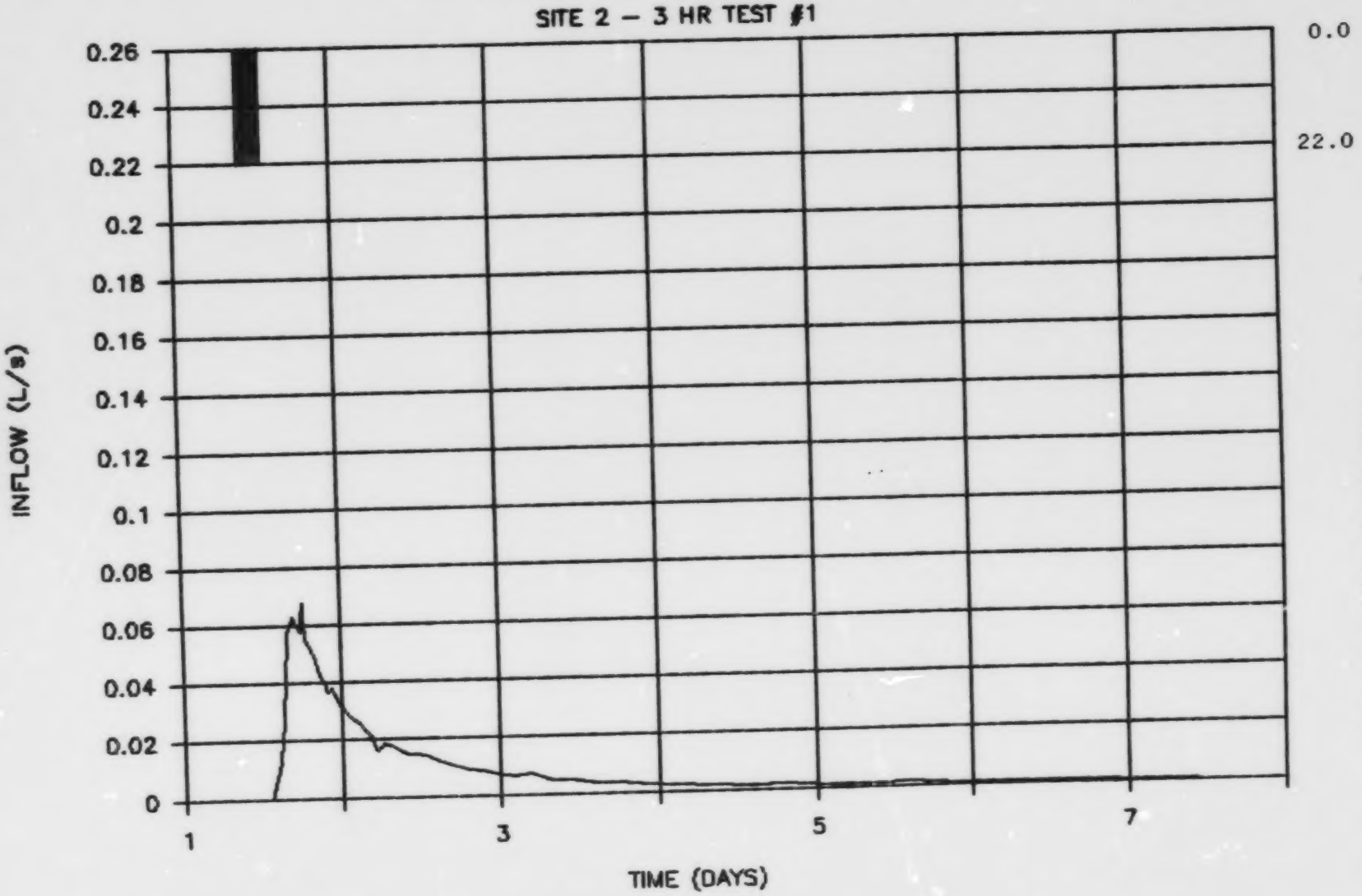

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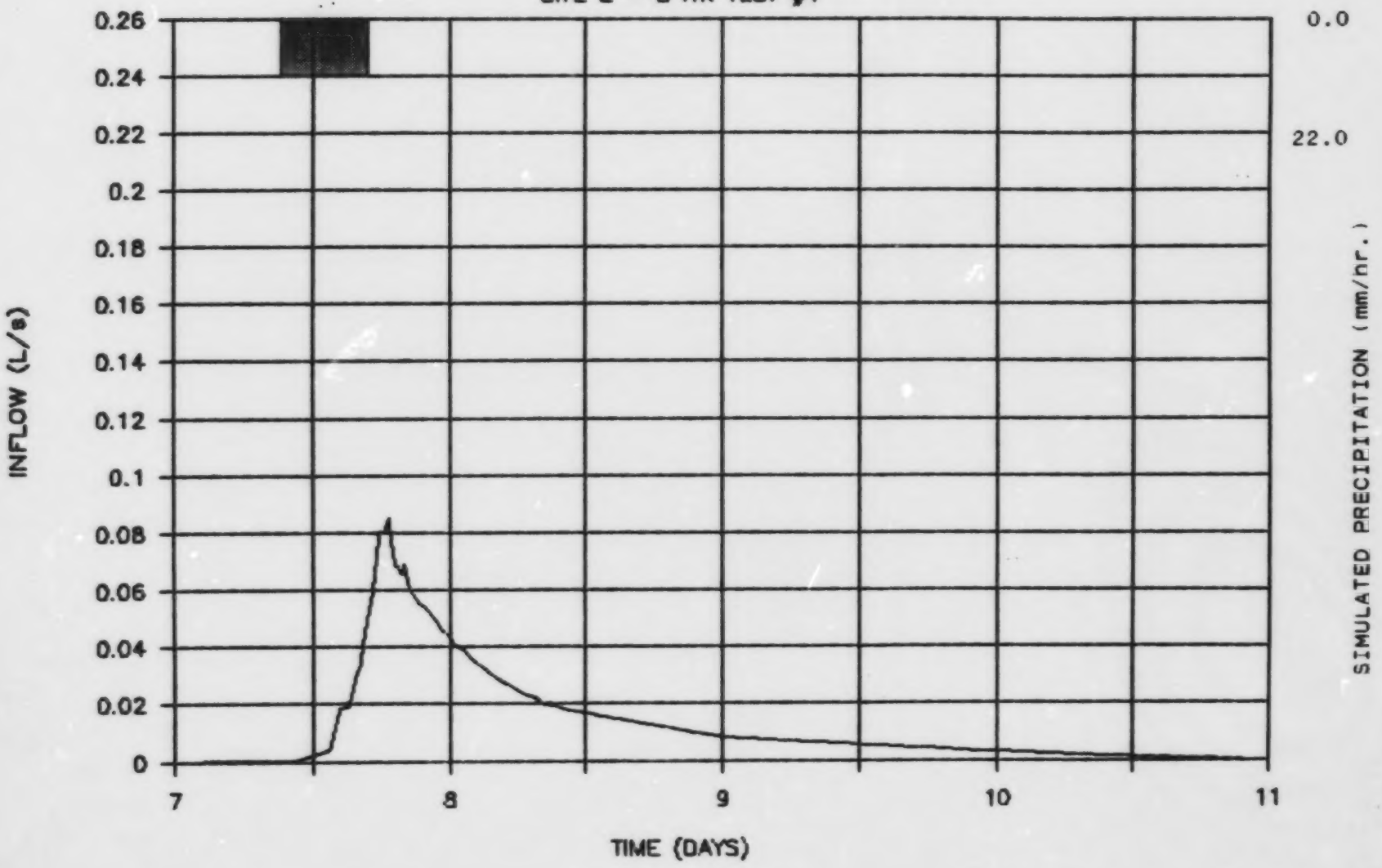

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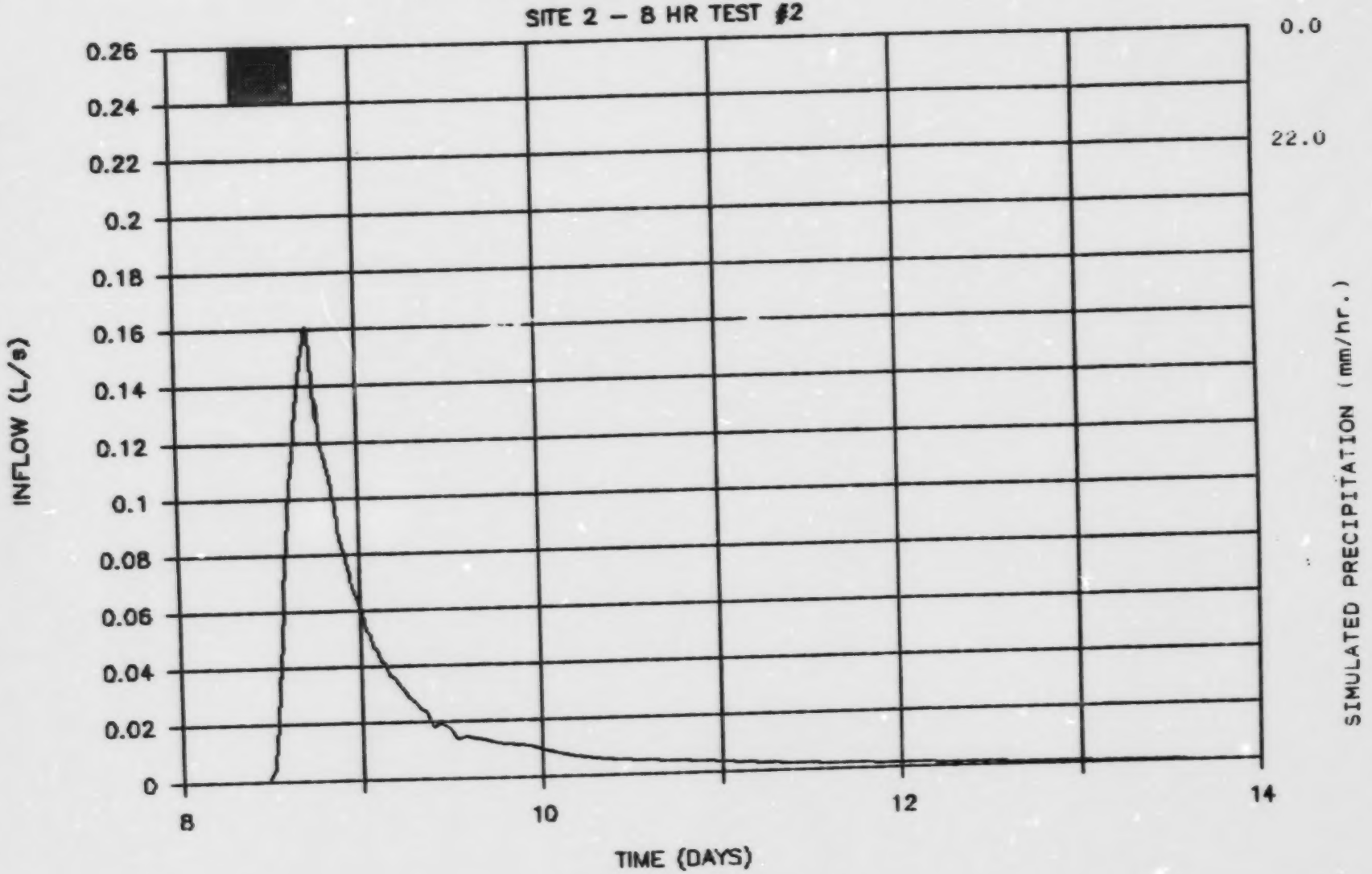

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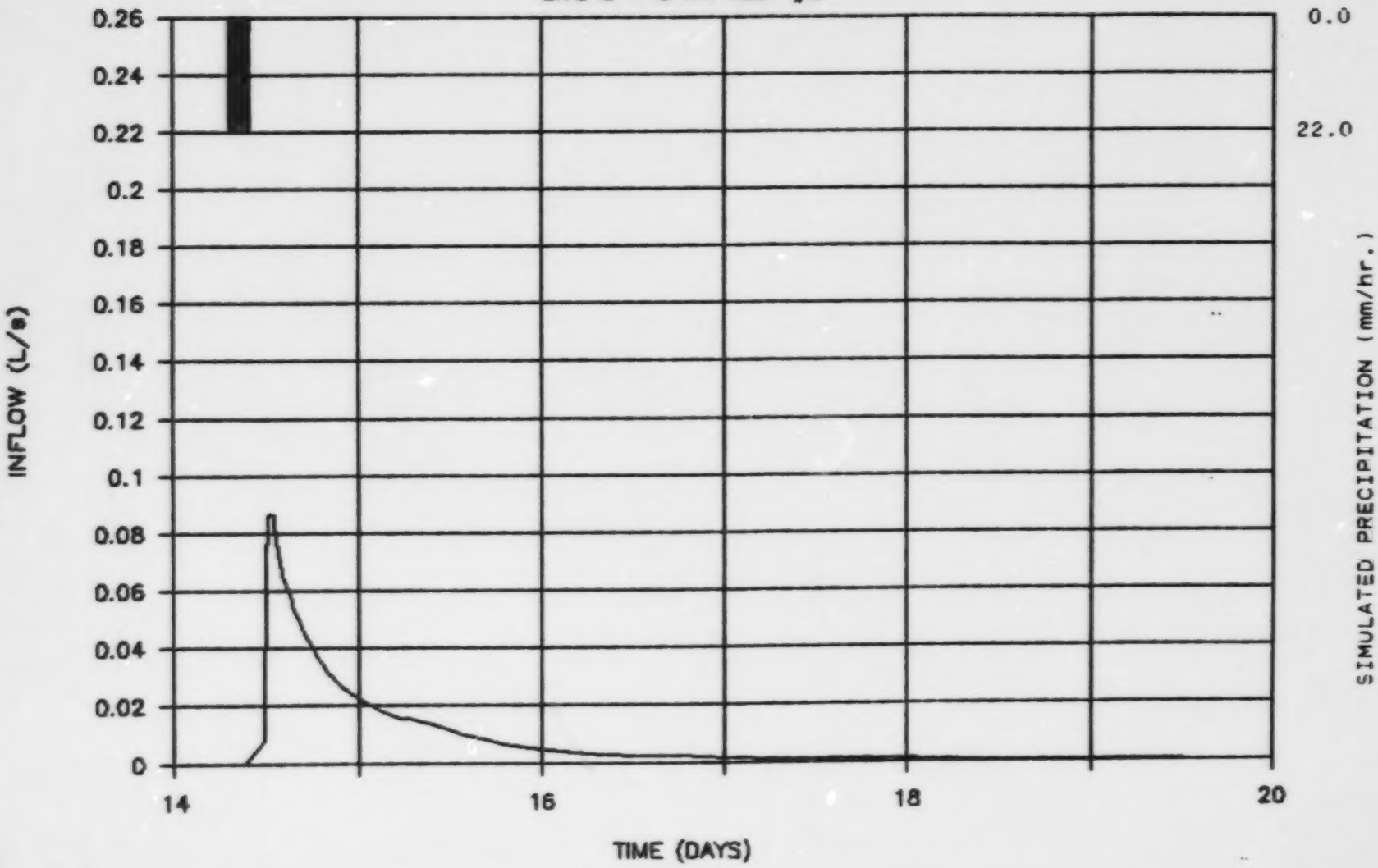


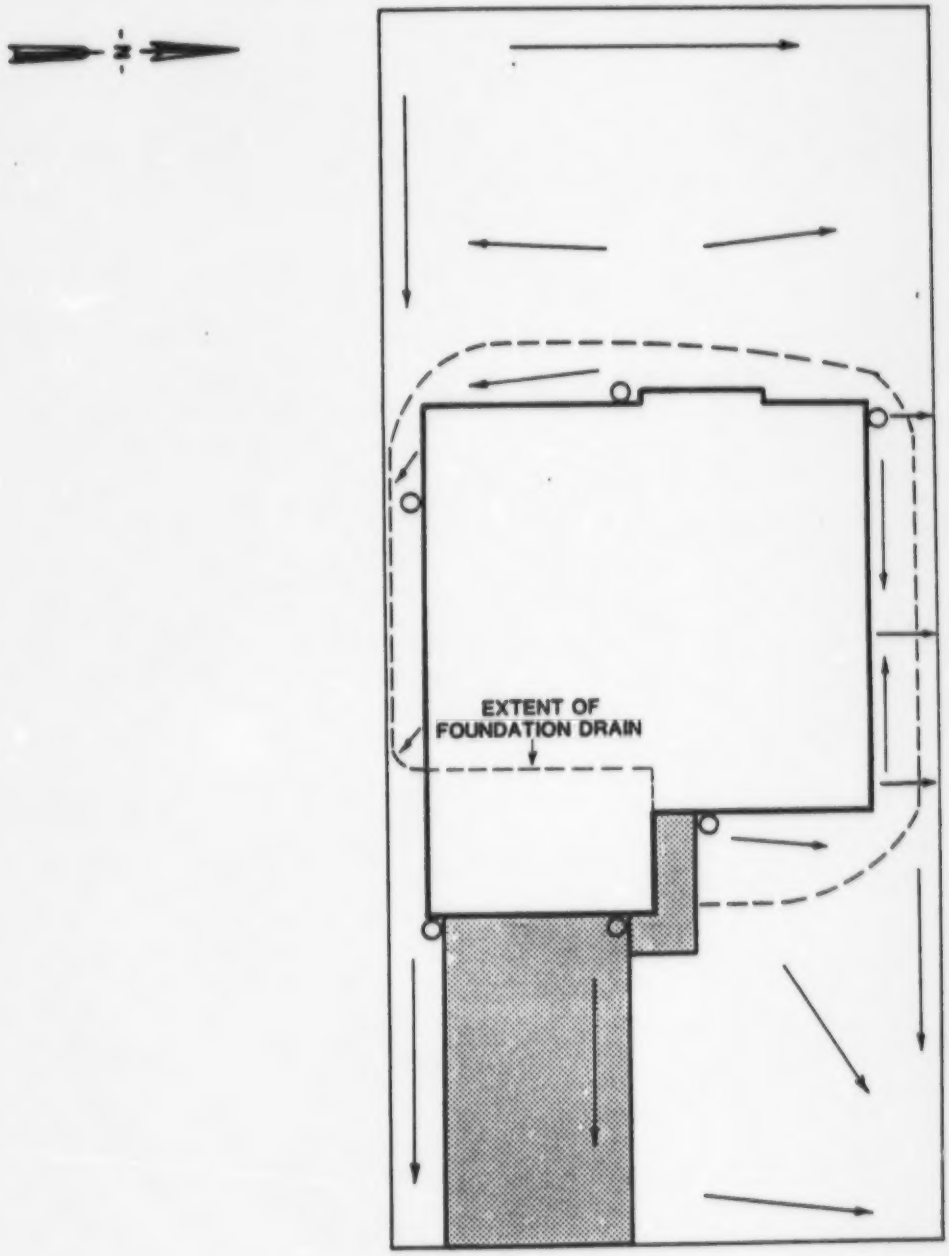
SITE 3

Six simulations were carried out. Two were variations designed to partially fulfill requirements for testing a sixth site, which was unavailable. The first three simulations and the fifth were those originally specified. The fourth simulation was a 3-hour event with no roof leader flows and the last was a simulation of roof leader flows only with their discharges next to the house.

In the fifth simulation, the 8-hour dry antecedent test, the pump ran for several extended periods which resulted in lost data. These records were, therefore, not used.

Site Data Summary

Roof area - 167 m^2
Lot area - 393 m^2
Lot area contributing to foundation drain flows - 69 m^2
Pump rate - 1.94 L/s, based on discharge measurement

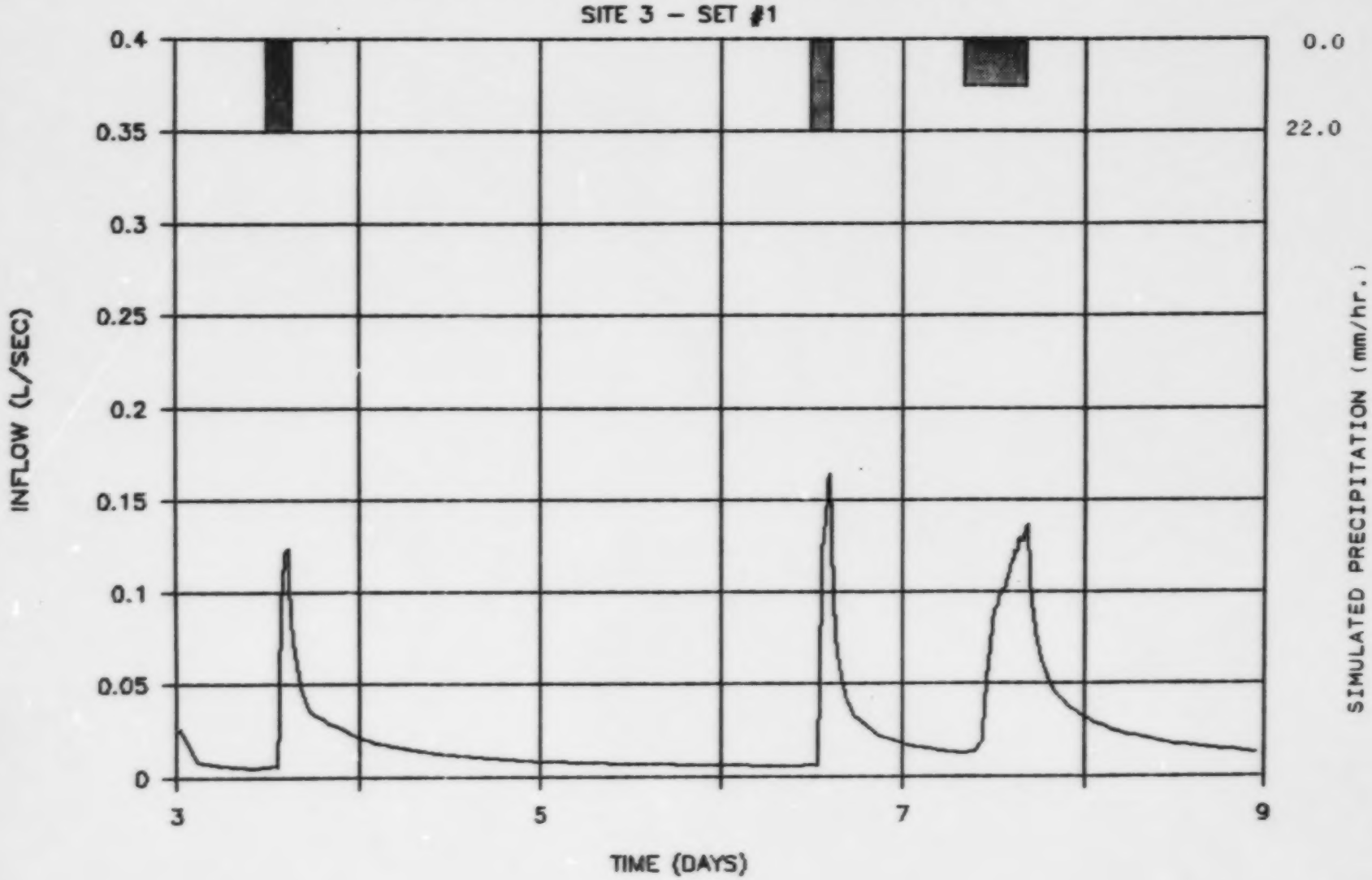


SITE 3
ROOF AREA 167m^2
GROUND AREA 393m^2

——— DRAINAGE DIRECTION
- - - - CONTRIBUTING AREA
O DOWNSPOUT

CH2M HILL

TEST PROGRAM RESPONSE



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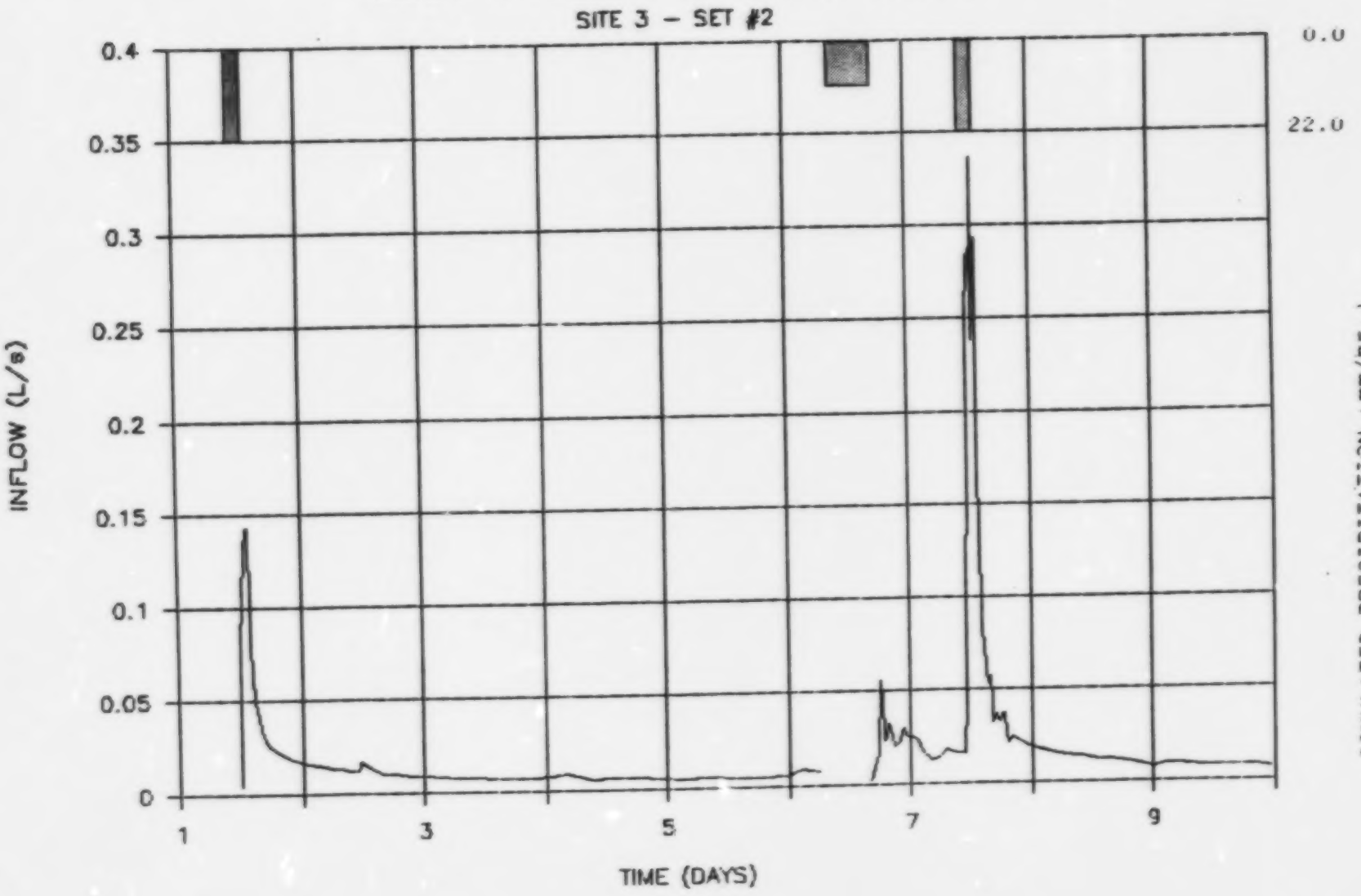

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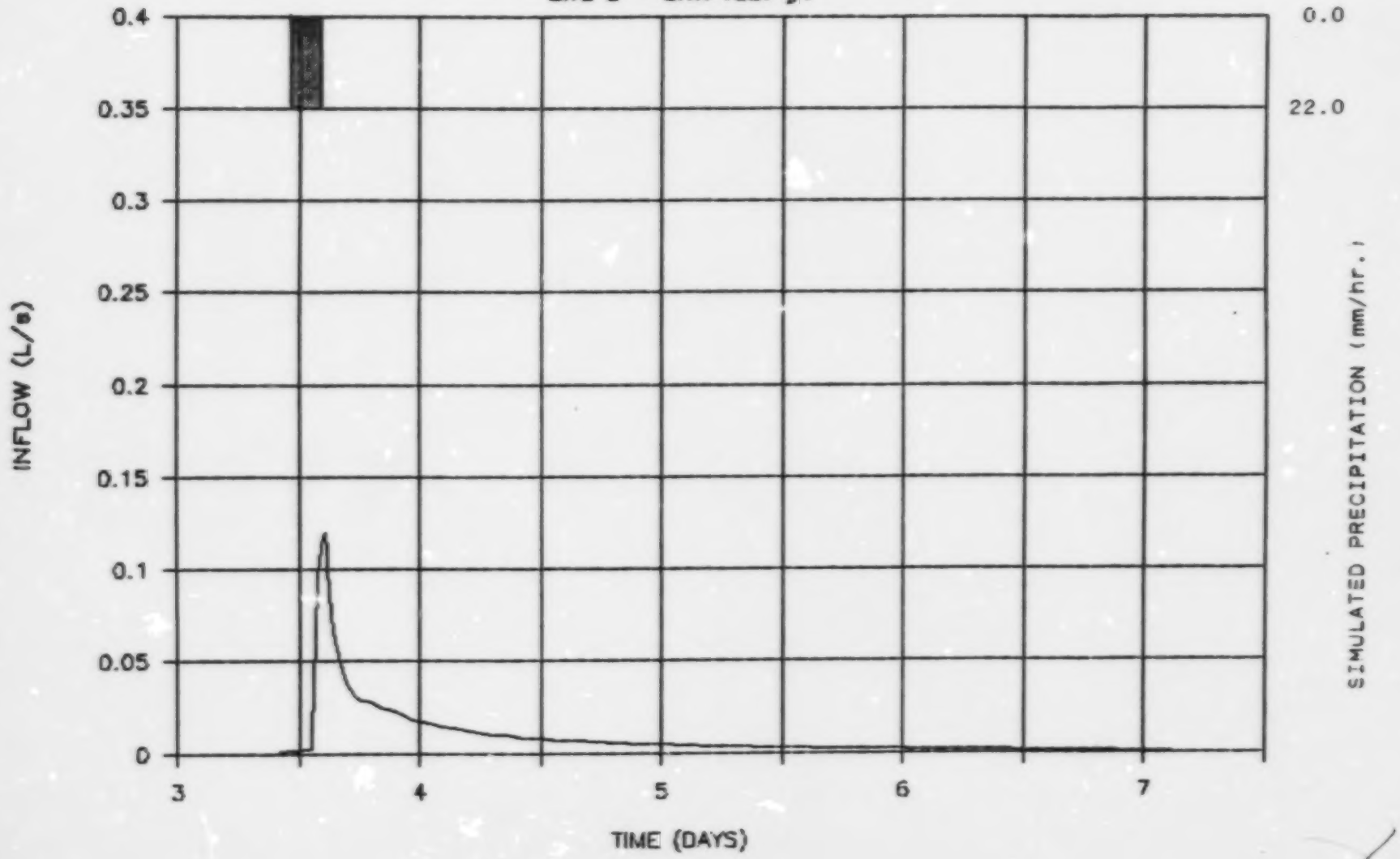

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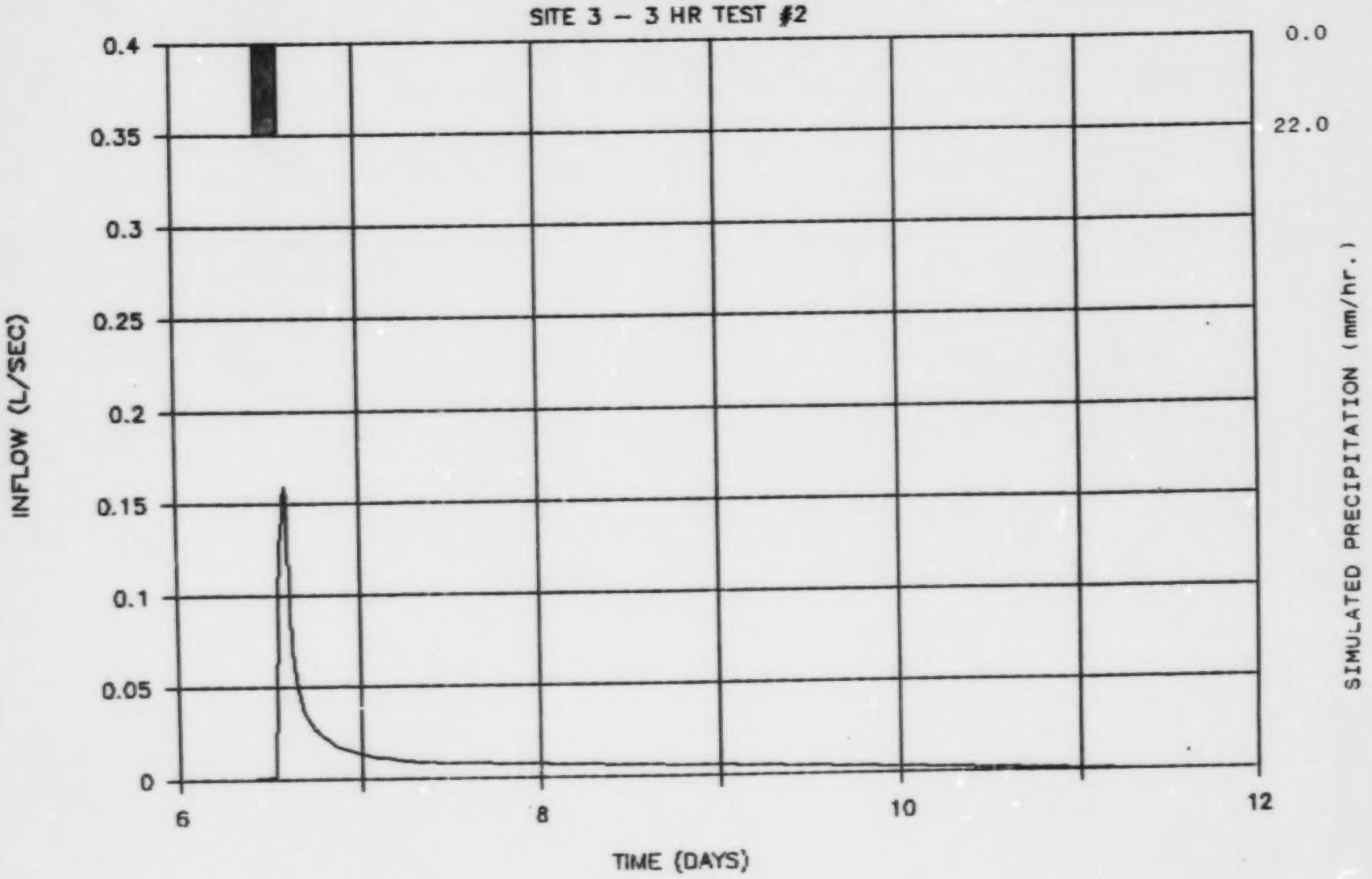
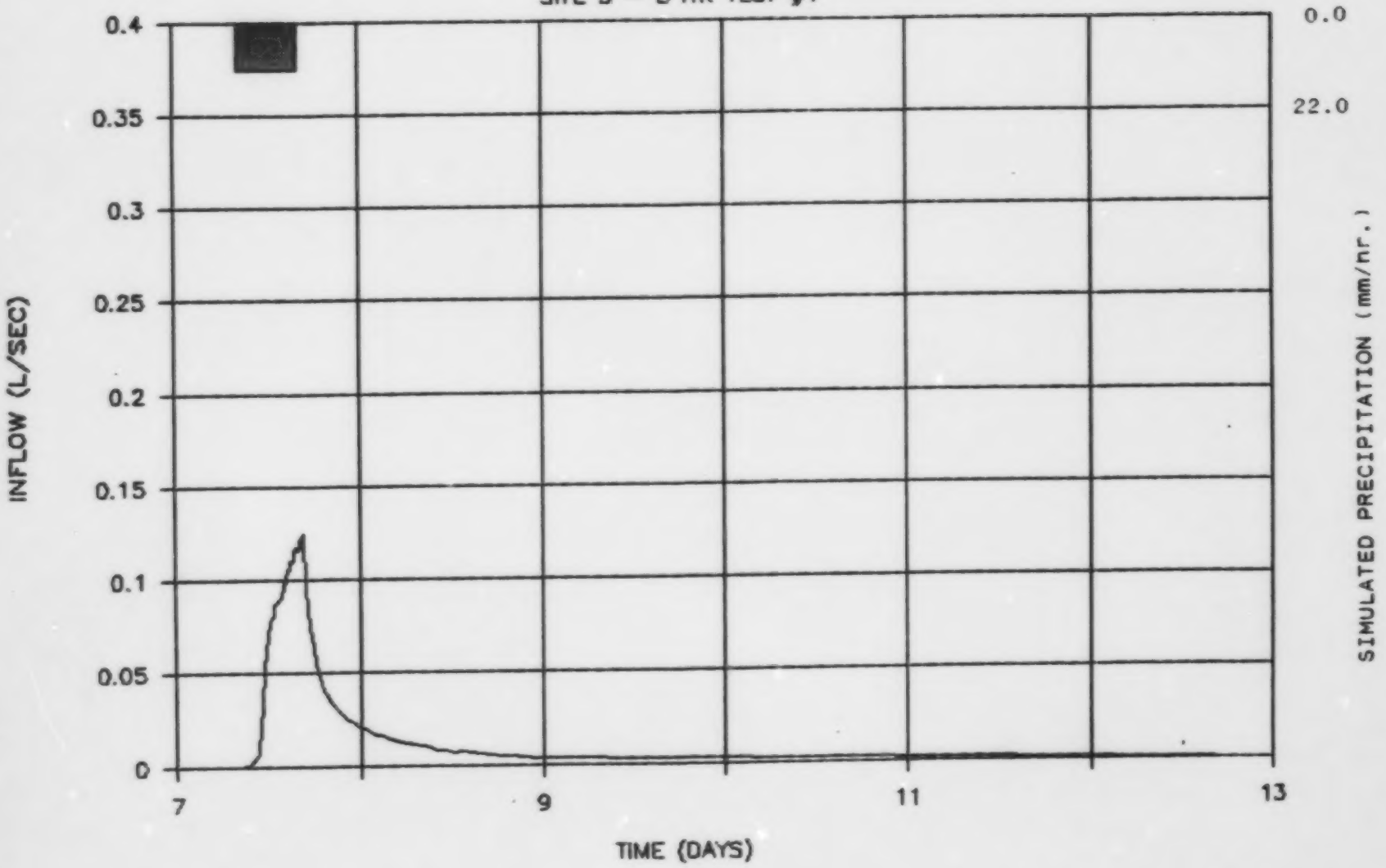


3 HR TEST RESPONSE

SITE 3 – 8 HR TEST #1



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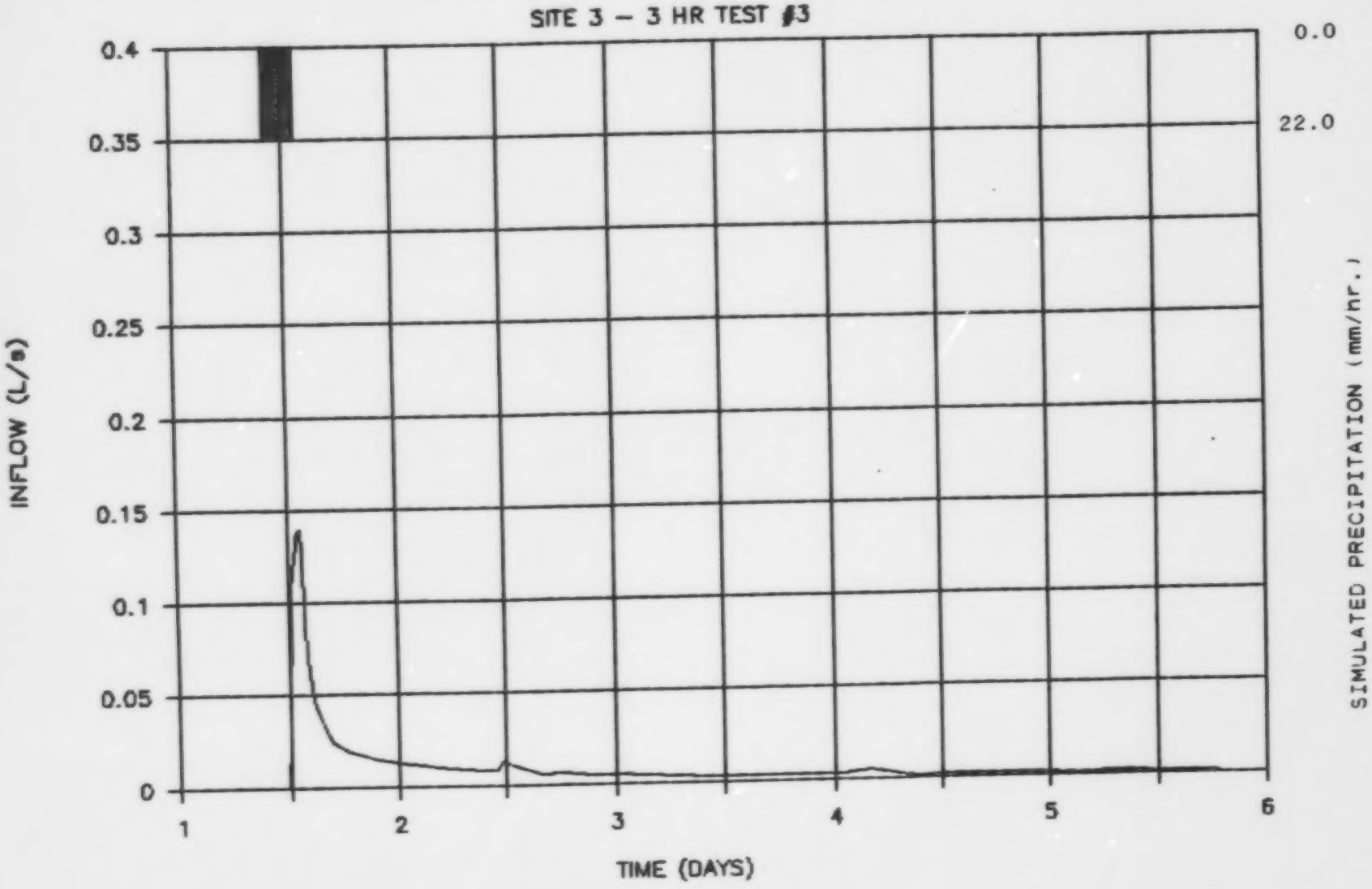

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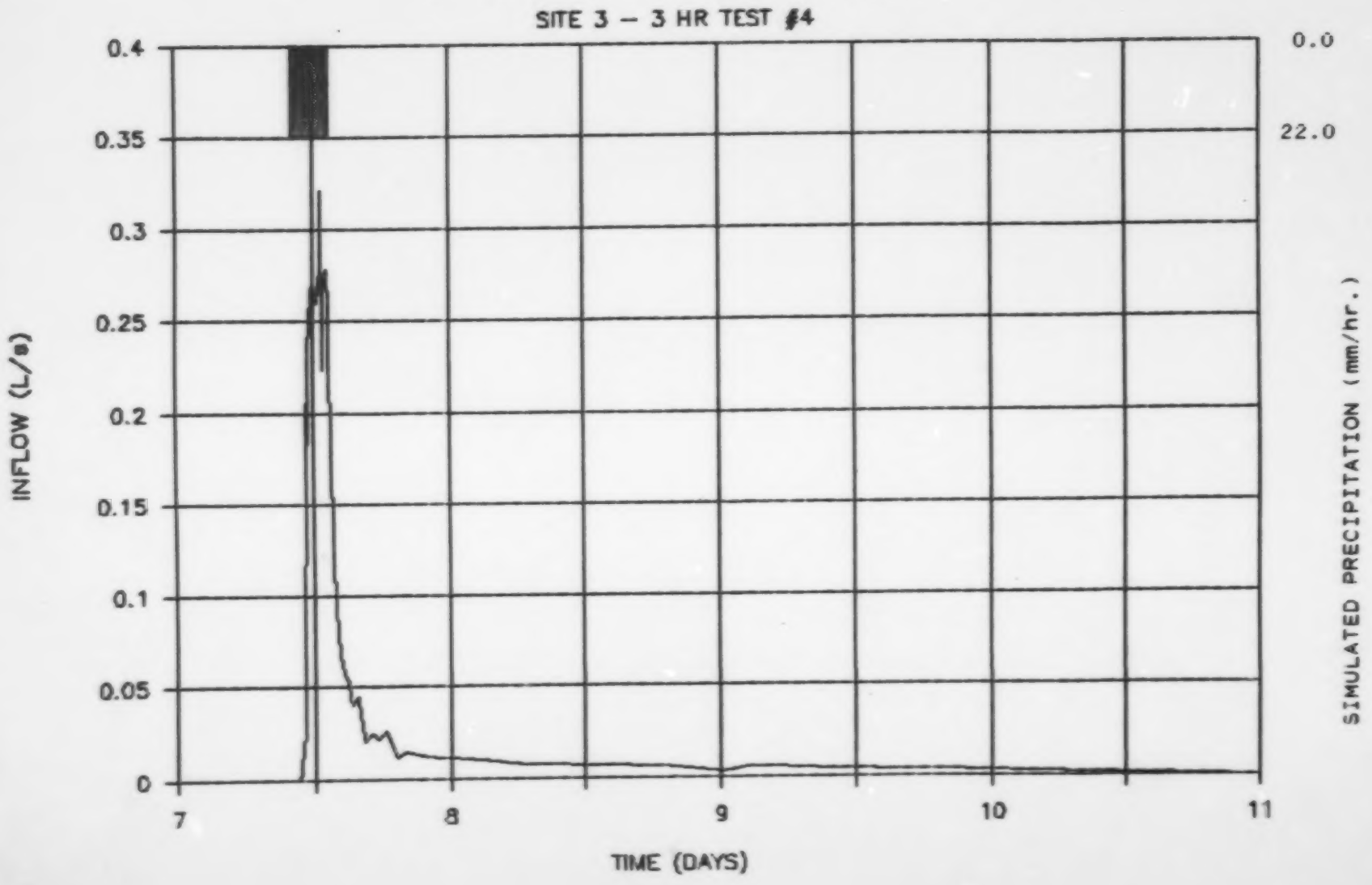
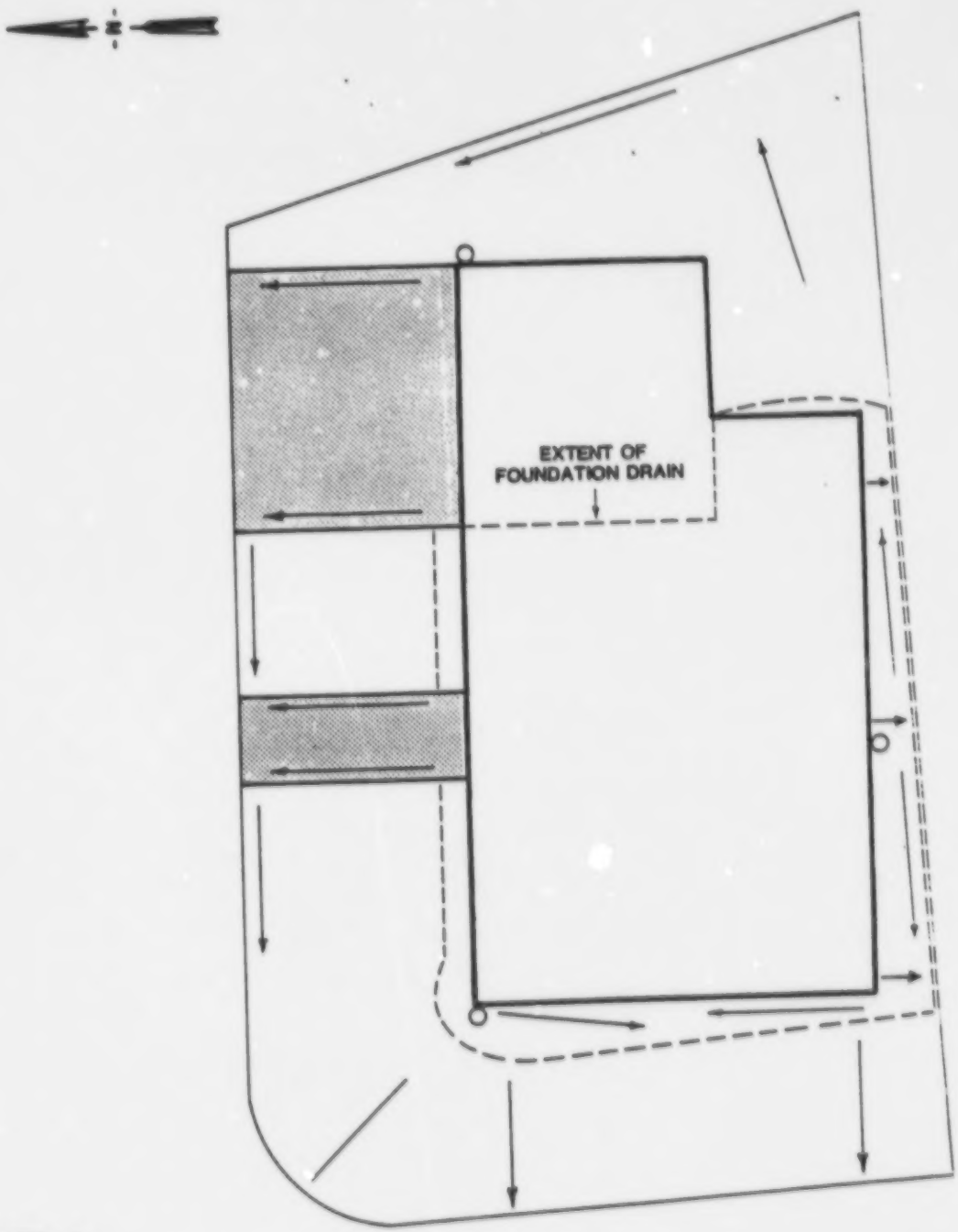


SITE 4

The four originally specified simulations were carried out.

Site Data Summary

Roof area - 272 m^2
Lot area - 327 m^2
Lot area contributing to foundation drain flows - 67 m^2
Pump rate - 0.88 L/s, based on discharge measurement

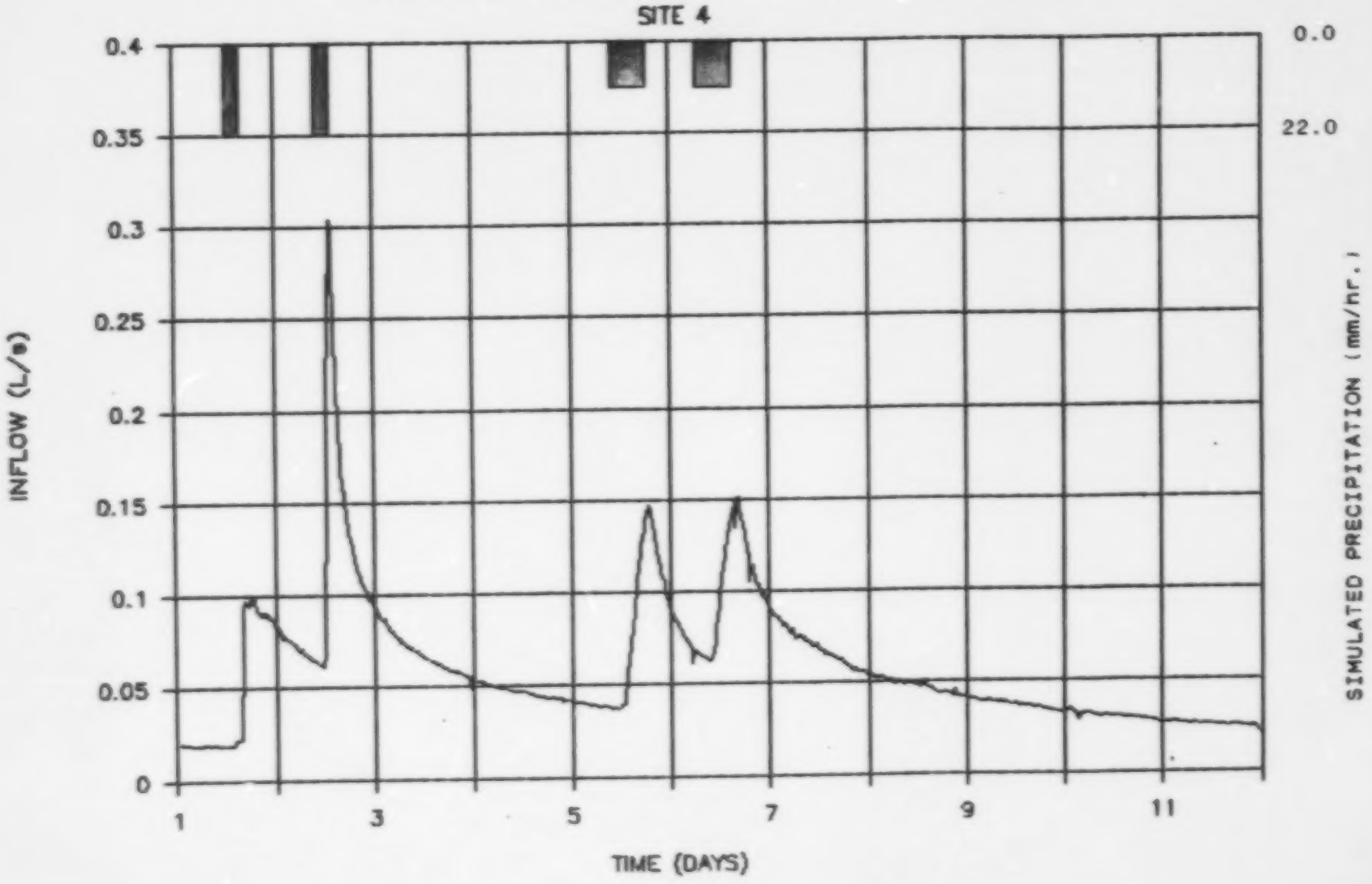


SITE 4
ROOF AREA 272m^2
GROUND AREA 329m^2

——— DRAINAGE DIRECTION
- - - - CONTRIBUTING AREA
○ DOWNSPOUT

CH2MHILL

TEST PROGRAM RESPONSE



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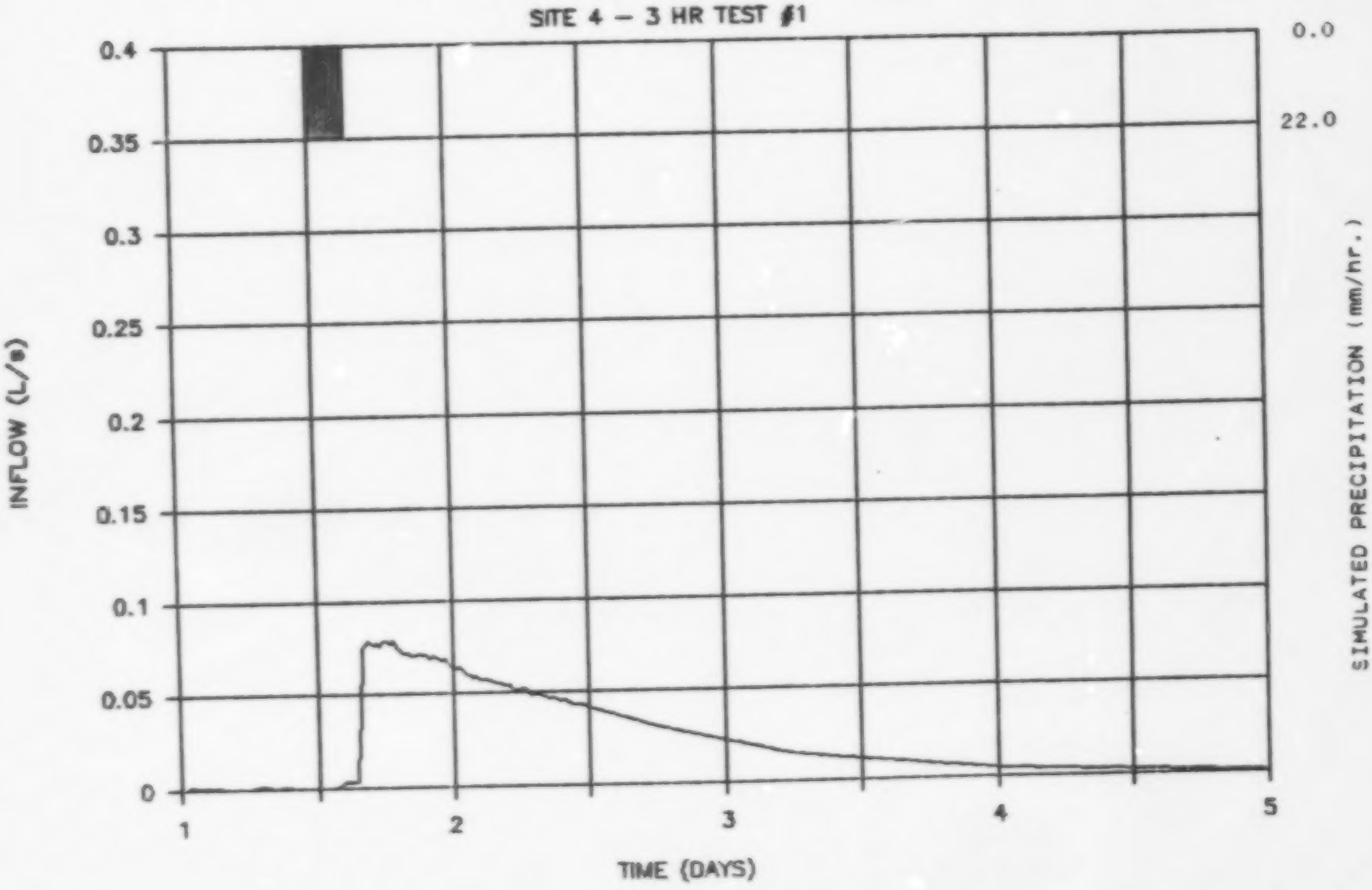

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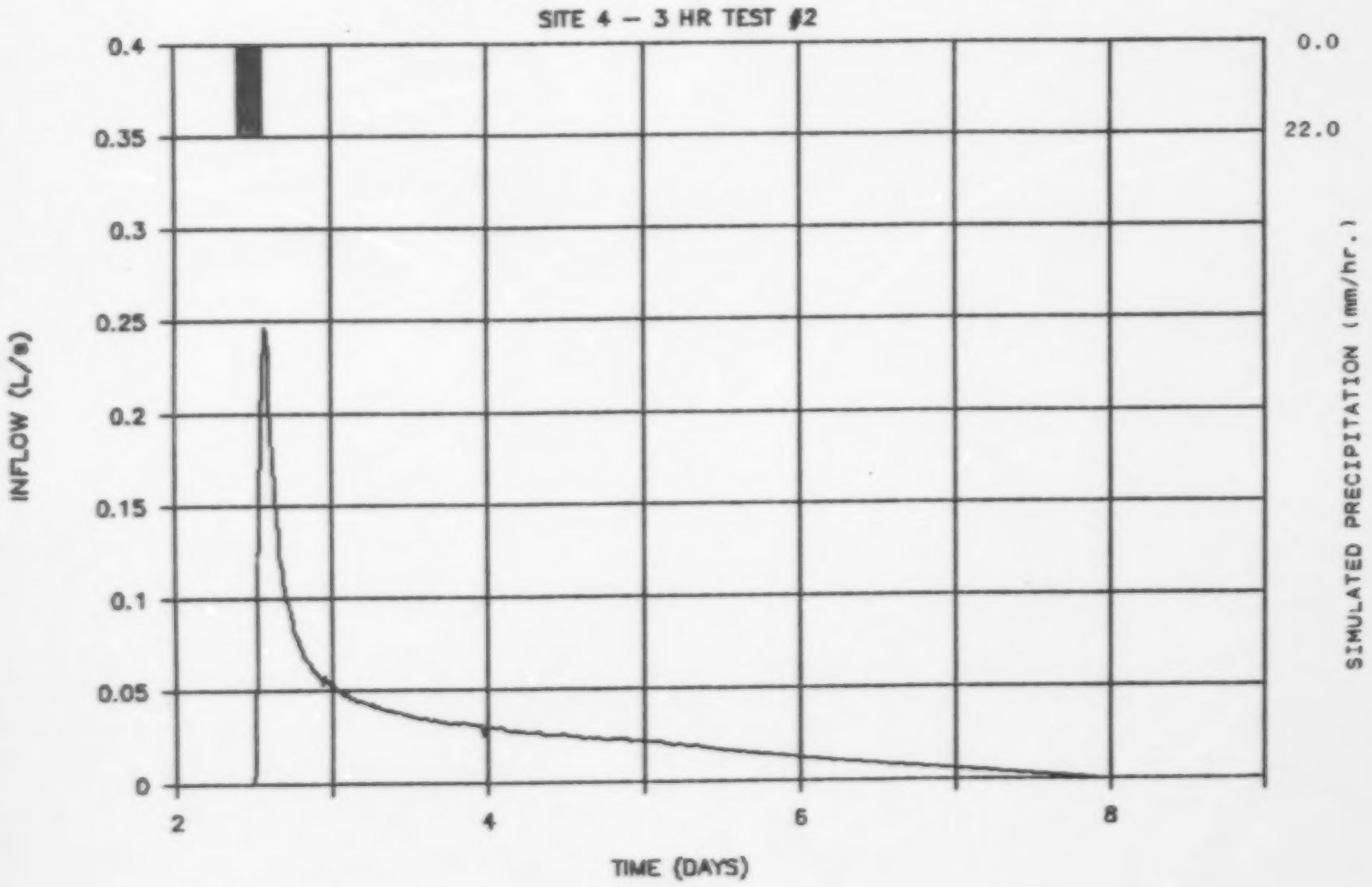
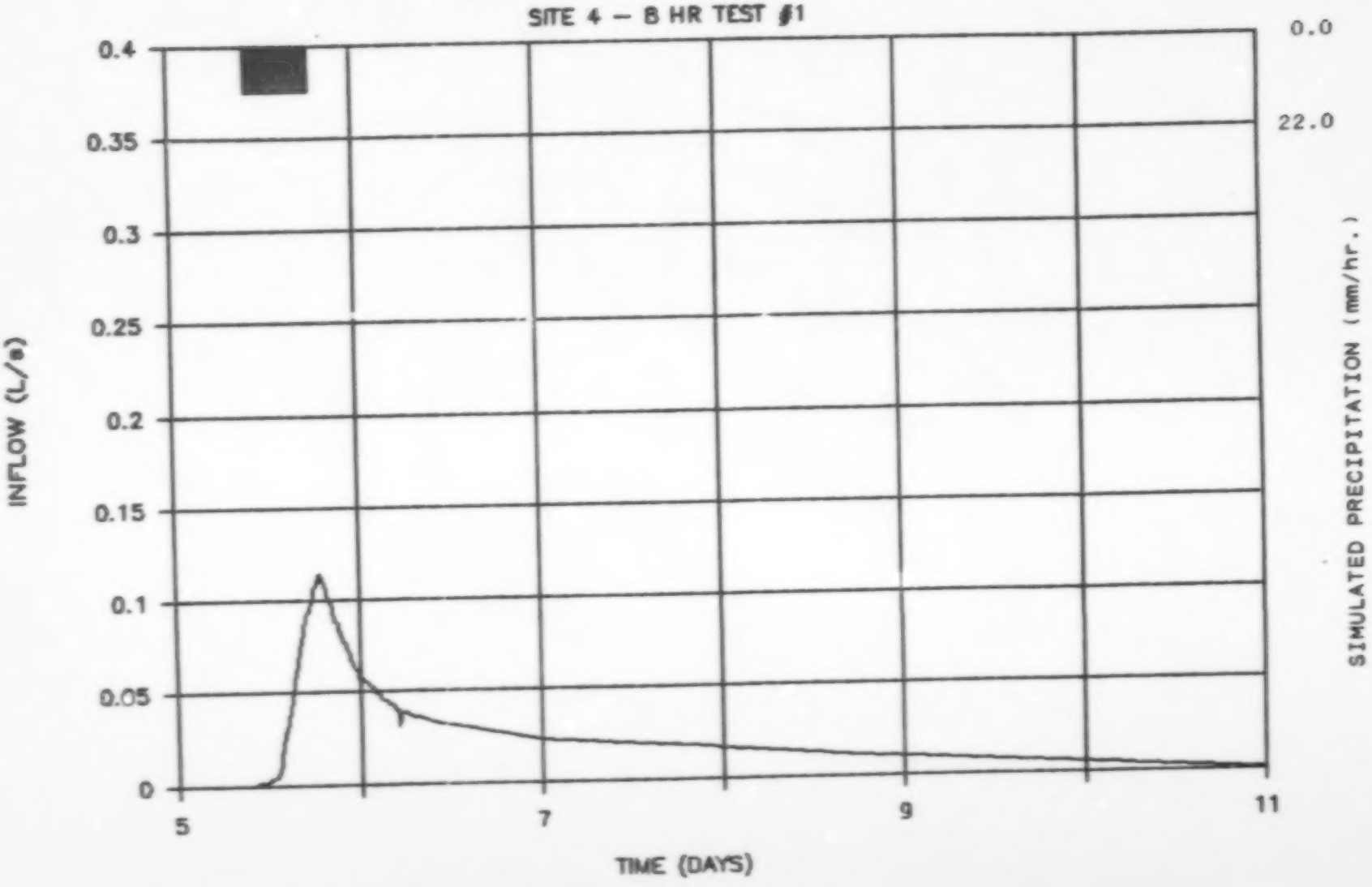


8 HR TEST RESPONSE



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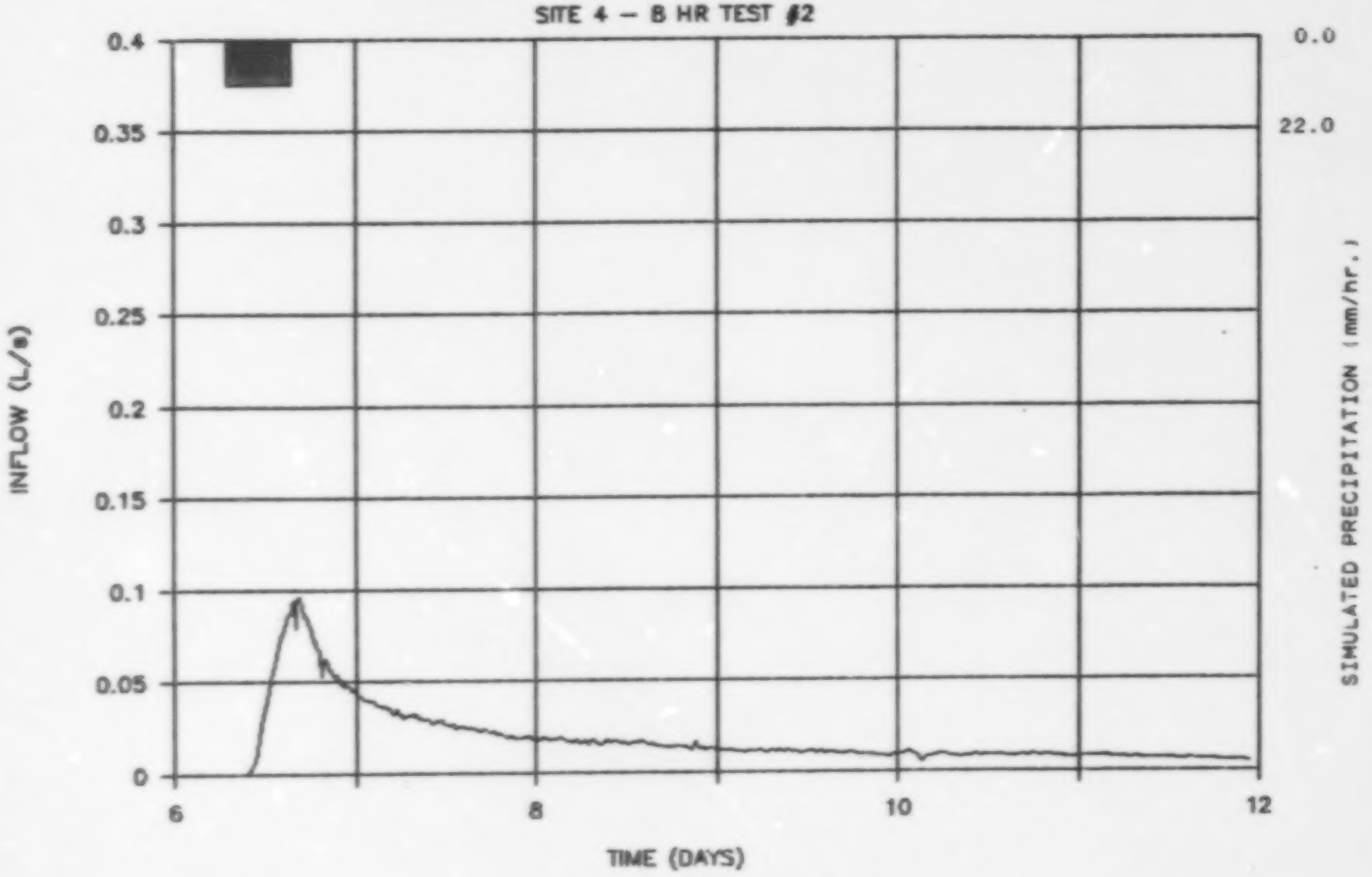


SITE 5

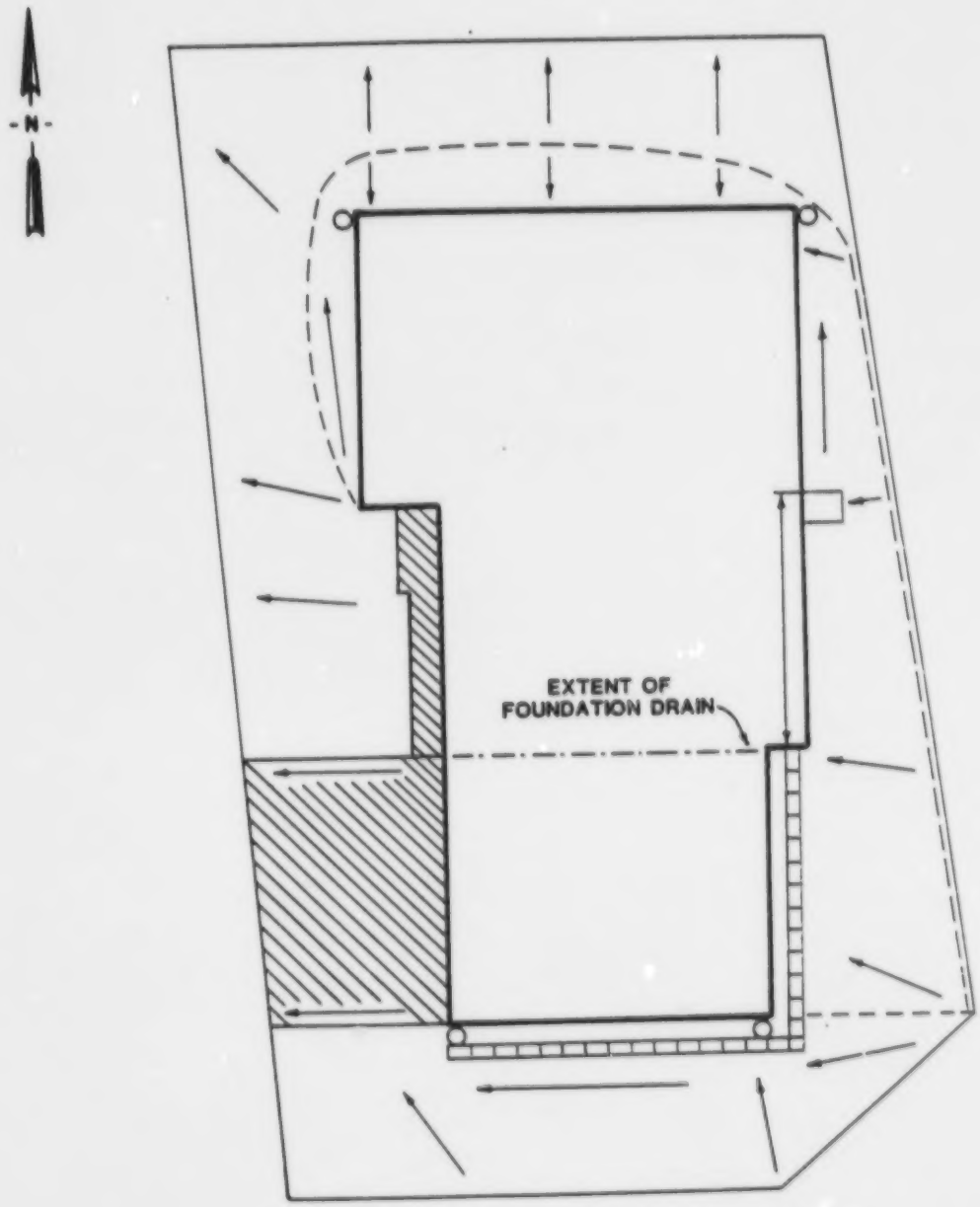
Four simulations, as originally specified, were carried out. During the first simulation a window well filled with water. The rest of the simulations were modified to prevent this reoccurrence.

Site Data Summary

Roof area - 261 m^2
Lot area - 379 m^2
Lot area contributing to foundation drain flows - 123 m^2
Pump rate - 1.93 L/s, based on sump drawdown

Note: At this residence both the sump pump discharge and the roof leader discharges were directed away from the home via shallow buried pipes. All terminations were over 5 m from the residence.

This was the only residence in which the sump and pump were installed after construction.



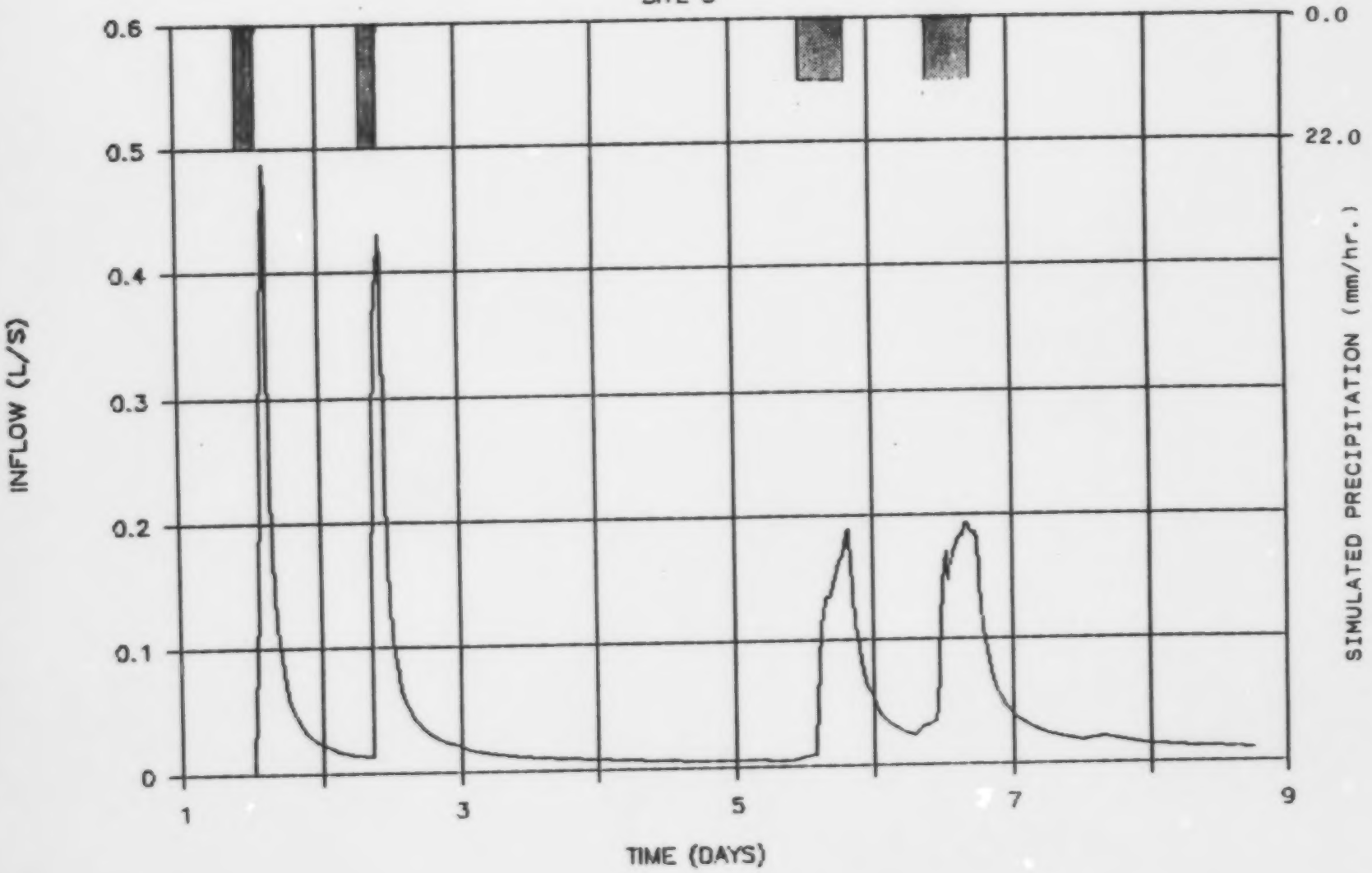
SITE 5
ROOF AREA 261m^2
GROUND AREA 379m^2

——— DRAINAGE DIRECTION
– – – – CONTRIBUTING AREA
○ DOWNSPOUT

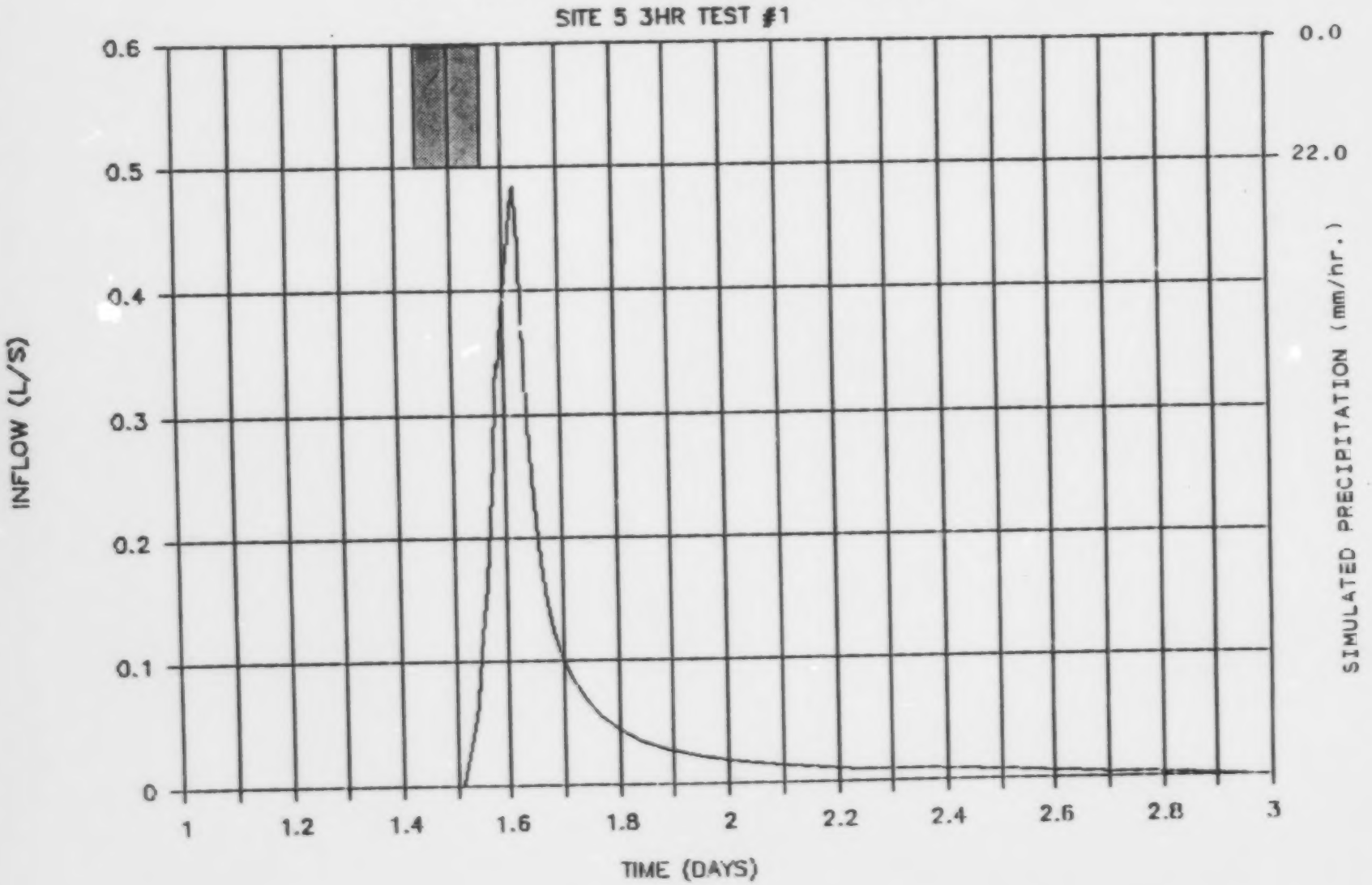
CH2M HILL

TEST PROGRAM RESPONSE

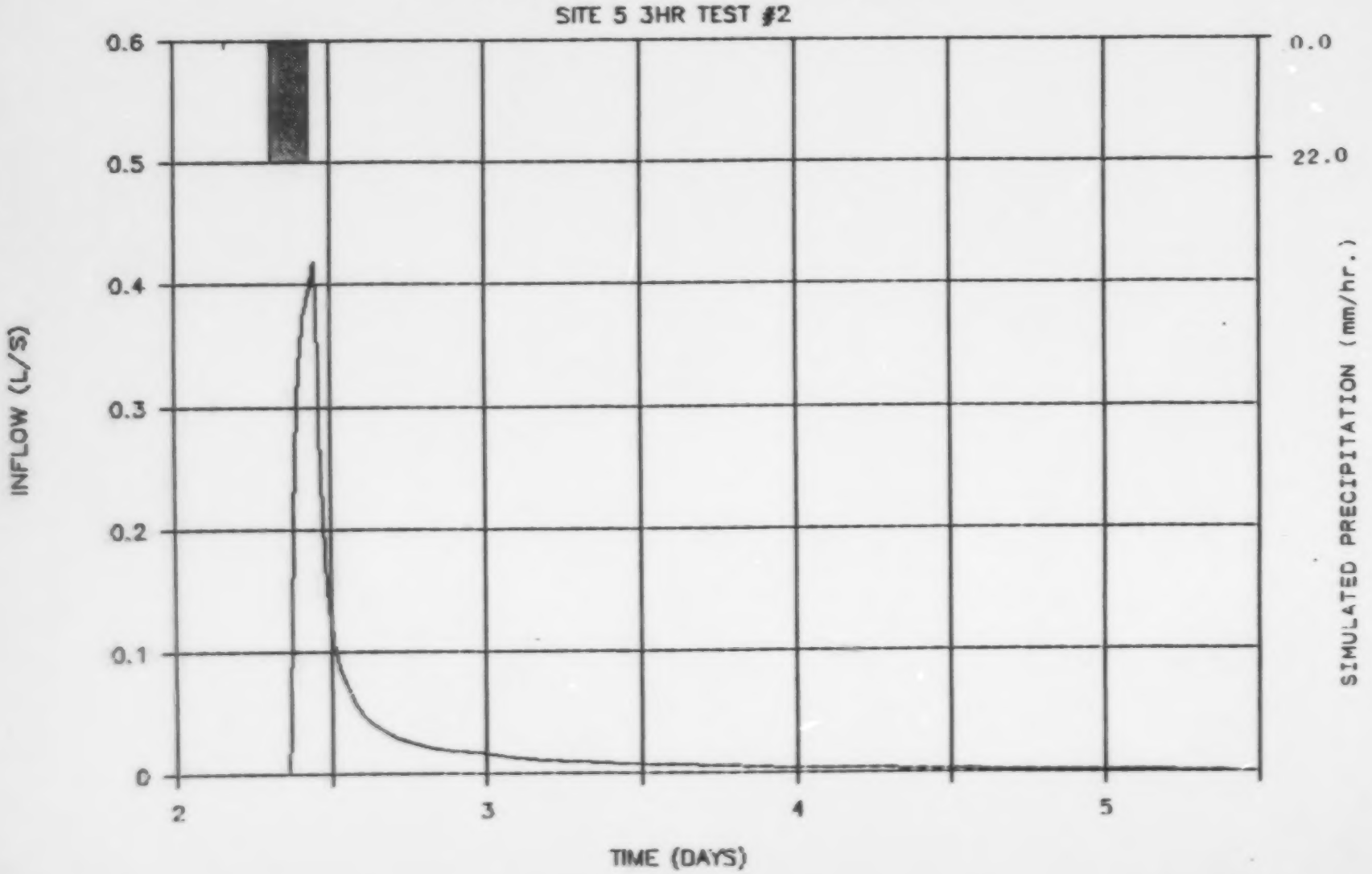
SITE 5



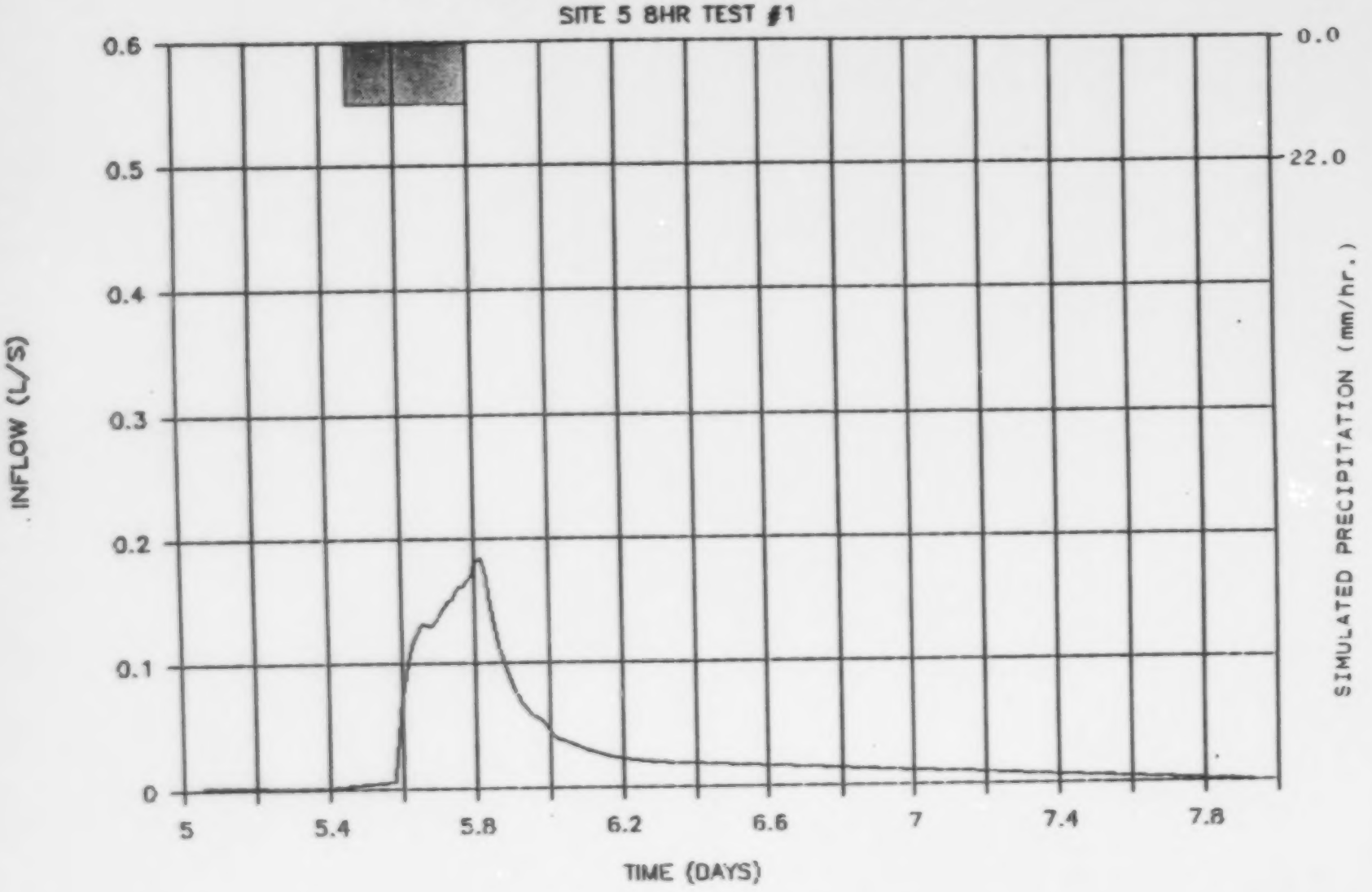
3 HOUR TEST RESPONSE



3 HOUR TEST RESPONSE



8 HOUR TEST RESPONSE



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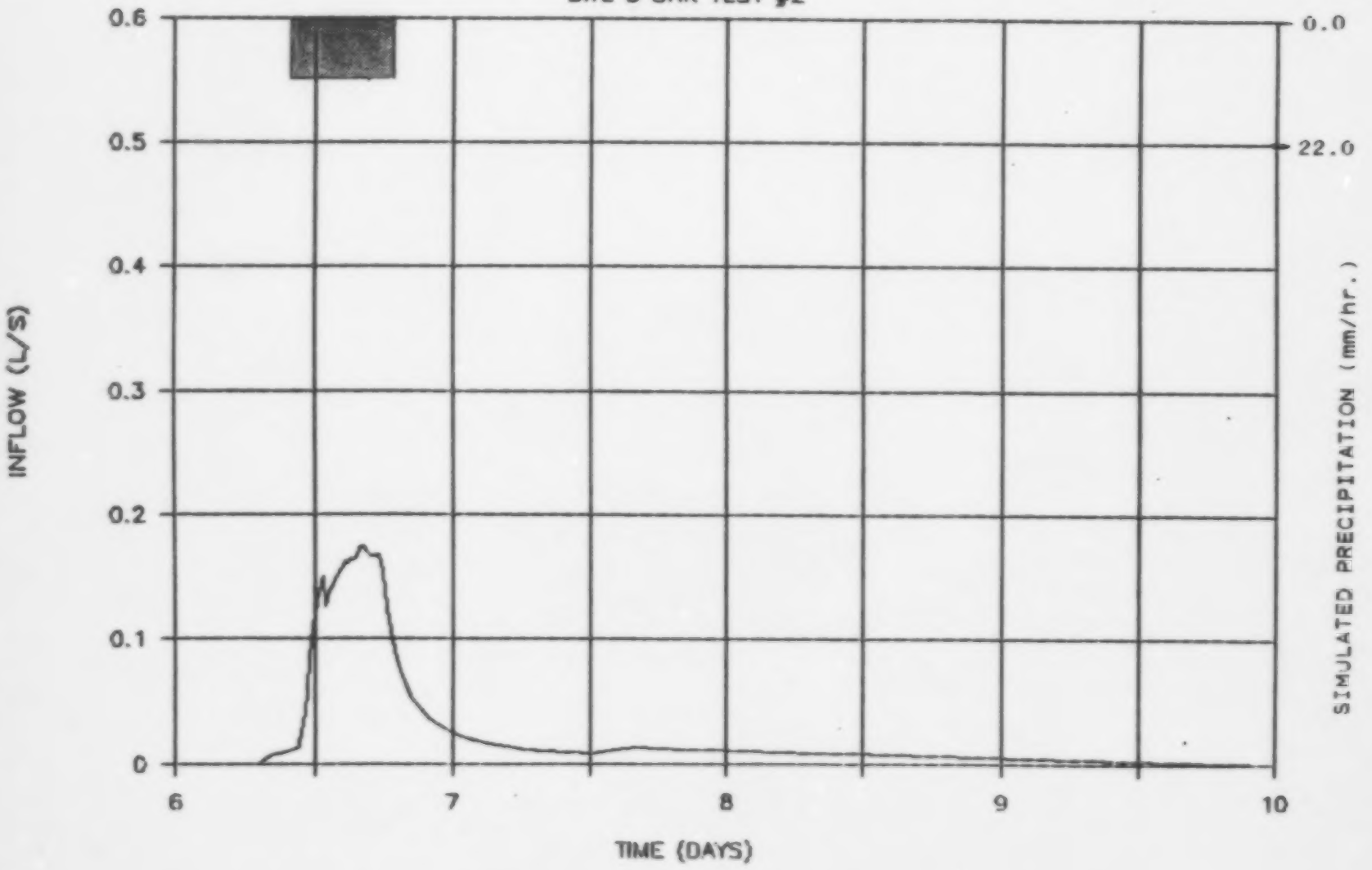

Appendix B
GEOTECHNICAL INVESTIGATION

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

Our Project No. EG-06834
Your Reference No.

September 18, 1989

CH2M Hill Company Ltd.
203 10240 - 124 Street
Edmonton, Alberta
T5N 3W6

Attention: Mr. George Bontus, P.Eng.

Dear Sir:

Re: Weeping Tile Study
Various Sites in City of Edmonton

Thie letter presents the results of a limited subsoil investigation performed at 5 sites in various residential subdivisions within the City of Edmonton. It is understood soils data gathered in this investigation will be used for your study of weeping tiles in flows.

The purpose of the investigation was to determine subsurface soil profile, moisture contents and estimate the permeability of the soils.

From July 20 to August 24, 1989, at the five different sites, two hand auger holes were drilled to a depth of 2.45 m, using a 50 mm diameter Dutch auger. One hole was drilled within 1.5 m of the existing house, while the other hole was drilled approximately 5 to 8 m further back from the house. Each hole was drilled to a depth of 2.44 m. The description of the soil profile, water content and permeability estimates are given on the attached pages.

The soils were visually logged in the field, disturbed samples were taken at random depths for moisture content determinations. Bag samples of soil were retained for possible further testing.

It should be recognized that the permeability values are estimated to range within two orders of magnitude. No field or laboratory permeability tests have been carried out. The range of permeability are estimates based upon the soil description correlated with values cited in literature and judgement.

We trust that the information provided will suffice your requirements and that Hardy BBT Limited can be of service to your company in the future.

Respectfully submitted

Hardy BBT Limited

Charles Ahlf, C.E.T.
Geotechnical Division

Reviewed by:

M.J. Cherniawski, P.Eng.
Geotechnical Division

CA/lmh
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SITE 1

Drilled: July 20, 1989

Test Hole #1 (close to house)

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .15	TOPSOIL, silty clayey low plastic, black		1×10^{-4} to 1×10^{-5}
.15 - .45	CLAY FILL, organic, low to medium plastic, black		1×10^{-4} to 1×10^{-6}
.45 - 2.2	CLAY TILL, silty, sandy, firm to stiff, medium to high plastic, brown, topsoil inclusion, brick, pebbles	@ .6 m - 20.2% @ 1.5 m - 25.2%1	1×10^{-6} to 1×10^{-8}
@ 2.2 m	GRAVEL, top of weeping tile END OF HOLE @ 2.2 m No visible water @ completion	@ 2.2 - 28.1%	

Test Hole #2

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .21 m	TOPSOIL, silty, clayey, low plastic, black		1×10^{-4} to 1×10^{-5}
.21 - .35	CLAY FILL - silty, sandy medium to high plastic, brown to black, topsoil inclusions		1×10^{-5} to 1×10^{-7}
.35 - 2.1	CLAY - silty, trace of sand,stiff high plastic, brown, rust stains	@ .6 m - 14.2%	1 x 10-7 to 1×10^{-9}
@ 1.68	- sandier, medium plastic, firm to stiff, TRACE OF WATER, silt pockets	@ 1.5 m - 23.7 %	1×10^{-6} to 1×10^{-8}
2.1 - 2.44	CLAY TILL - silty, sandy, medium plastic, stiff, grey-brown END OF HOLE @ 2.44 TRACE OF FREE WATER	@ 2.3 - 26.0%	1×10^{-7} to 1×10^{-9}

SITE 2

Drilled: July 20, 1989

Test Hole #3 (close to house)

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .15 m	TOPSOIL FILL, silty, sandy black		1×10^{-3} to 1×10^{-5}
.15 - 2.39	CLAY FILL, silty, sandy, firm, medium plastic, brown, sand pockets, topsoil inclusions	@ .6 m - 14.2% @ 1.5 m - 23.7%	1×10^{-6} to 1×10^{-7}
@ 1.8	TRACE OF FREE WATER	@ 2.3 m - 26.0%	
2.39 - 2.44	CLAY, silty stiff, high plastic mottled grey-brown		1×10^{-7} to 1×10^{-8}
	END OF HOLE 2.44 m TRACE OF WATER @ 2.44 m on Completion		

Test Hole #4

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .76	TOPSOIL FILL, sandy, silty, black	@ .6 - 14.5%	1×10^{-3} to 1×10^{-5}
.76 - .99	SAND, silty, fine grained, grey		1×10^{-3} to 1×10^{-4}
.99 - 2.44	SAND, silty, fine grained, clayey, low plastic, grey, with medium plastic clay pockets,	@ 1.5 m-18.3%	1×10^{-2} to 1×10^{-4}
@ 1.8	FREE WATER	@ 2.44 - 26.7%	
	END OF HOLE @ 2.44 m WATER @ 2.3 m at Completion		

SITE 3

Drilled: July 20, 1989

Test Hole #5 (close to house)

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .15	TOPSOIL FILL, silty, clayey firm, black		1×10^{-3} to 1×10^{-5}
.15 - 2.3	CLAY FILL, silty, sandy, firm, medium plastic, brown wet sand pockets	@ .6 m - 25.2% @ 1.7 m - 20.8%	1×10^{-5} to 1×10^{-7}
@ 1.8	TRACE OF FREE WATER squeezing in		
2.3 - 2.44	CLAY, silty, sandy, medium plastic, stiff, mottled grey-brown, sand pockets	@ 2.44 m-28.6%	1×10^{-6} to 1×10^{-4}
	END OF HOLE @ 2.44 m TRACE OF FREE WATER @ 2.44 m		

Test Hole #6

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .10	TOPSOIL FILL, silty, clayey, firm, black		1×10^{-3} to 1×10^{-5}
.10 - 2.44	CLAY, silty, sandy, firm to stiff medium plastic, brown, salts, sand pockets	@ .6 m - 21.3% @ 1.5 m-24.1%	1×10^{-6} to 1×10^{-8}
@ 1.8 m	firm to stiff, TRACE OF FREE WATER	@ 2.44 m - 30.3%	
	END OF HOLE @ 2.44 m TRACE OF FREE WATER @ 2.44 m		

SITE 4

Drilled: August 17, 1989

Test Hole #7 (close to house)

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .10	TOPSOIL FILL, silty, sandy firm, black		1×10^{-3} to 1×10^{-5}
.10 - 2.3	SAND FILL, with some clay pockets, fine to medium grained, brown to black compact, pieces of flagging	@ .6 m - 14.7% @ 1.5 m - 12.7%	1×10^{-3} to 1×10^{-4}
@ 2.3 m	Edge of weeping tile, FREE WATER		
2.3 - 2.44 m	CLAY, silty, some sand, medium to high plastic, brown, silt pockets	@ 2.4 - 16.0%	1×10^{-6} to 1×10^{-7}
	END OF HOLE @ 2.44 m WATER @ 2.3 m at Completion		

Test Hole #8

Depth (m)	Soil Description	Moisture Content	Estimated K cm/sec
0 - .10	TOPSOIL FILL, silty, sandy, firm, black		1×10^{-3} to 1×10^{-5}
.10 - 3.0	SAND & CLAY FILL, silty, low plastic, compact brown to black		1×10^{-3} to 1×10^{-7}
.30 - 1.4	SAND, trace of silt, medium grained, brown, occ. pebble	0.6 m - 5.3%	1×10^{-2} to 1×10^{-3}
1.4 - 2.44	CLAY, silty, some sand, firm medium to high plastic, grey brown, salts, occ. pebble	@1.5m-23.8% @ 2.4 m-25.5%	1×10^{-7} to 1×10^{-9}
	END OF HOLE @ 2.44 m DRY @ COMPLETION		

SITE 5

Drilled: August 24, 1989

Test Hole #9 (close to house)

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - 1.5	TOPSOIL FILL, silty sandy, low plastic, black		1×10^{-3} to 1×10^{-5}
.15 - .90	CLAY FILL, silty, sandy, medium plastic, stiff, brown topsoil pockets	@.6 m-21.2%	1×10^{-5} to 1×10^{-7}
.90 - 1.45	CLAY, silty, sandy, medium plastic, stiff, brown, occasional high plastic pockets silt pockets	@1.5 m-30.8%	1×10^{-5} to 1×10^{-7}
1.45 - 2.44	CLAY TILL, silty, sandy medium plastic, firm to stiff, brown, coal pockets	@2.4 m - 22.4%	1×10^{-6} to 1×10^{-4}
	END OF HOLE @ 2.44 m		
	HOLE DRY @ Completion		

Test Hole #10 (close to house)

Depth (m)	Soil Description	Moisture Content %	Estimated K cm/sec
0 - .23	TOPSOIL FILL, silty, sandy firm, black, clay pockets		1×10^{-3} to 1×10^{-5}
.23 - .90	CLAY FILL, silty, sandy medium plastic, brown topsoil inclusions, pebbles	@ 0.6 m-17.4%	1×10^{-5} to 1×10^{-7}
.90 - 1.60	CLAY, silty, sandy, stiff medium plastic, brown, sand pockets	@ 1.5 m-32.8%	1×10^{-5} to 1×10^{-7}
1.6 - 2.44 m	CLAY TILL, silty, sandy medium plastic, firm to stiff, brown, coal, pebbles		1×10^{-6} to 1×10^{-4}
@ 2.3 m	END OF HOLE @ 2.44 m	@ 2.4 m - 30.4%	
	TRACE OF WATER @ COMPLETION		

Appendix C
DESCRIPTION OF MODEL

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The model considers the flow of water through the backfill zone around a house. Two relationships are derived to calculate these flows:

- Depth of water above drains vs drain flow
- Infiltration rate vs rate of water table increase

A number of factors must be determined to derive the relationship.

1. Discharge to the foundation drain through the backfill is calculated using Darcy's Law for the chosen permeability (k). The depth of water vs drain flow relationship is derived from these calculations. The relationship is expressed in a mathematical formula which is input into the model.

2. The time for an increase in groundwater elevation for a particular depth, assuming that the foundation drain is operating, is calculated. This is based on the chosen soil characteristics and is carried out for various infiltration rates. The rate derived and expressed as a mathematical formula is again input into the model.

The model uses the rational formula to calculate the volume of runoff. Runoff coefficients and contributing areas must be input. This procedure is carried out for both roof flows and lot flows.

The calculation is done based on selected time steps.

- The runoff for the current time step is calculated.

- The water depth at the start of the current step is calculated.

- The depth of water and drain flow at the start of the previous time step are calculated. The excess infiltration during the previous step is calculated.

- The rate of water increase as a result of excess infiltration in the previous time step is calculated which determines the depth of water at the end of the current time step.

- The process is repeated for a specified time, at least until the tail end of the event is complete.